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AN EXPLANATION OF THE FALSE SPECTRA FROM DIFFRACTION GRATINGS.

By Theodore Lyman.

In a previous paper[1] the author has shown that the principal spectra produced by concave diffraction gratings are complicated by the presence of false spectra of lower order than the first and that these false spectra are common and often of excellent definition. It is the purpose of this paper to show that these false spectra are not of the nature of "ghosts" and that, while the theories developed to explain the latter cannot be made to fit them, a theory, proposed by Prof. Carl Runge after examining one of the plates which formed the basis of the earlier paper, furnishes an explanation of the phenomena.

The "ghost," so-called, is a faint reproduction of a real line and in general occurs within a few Ångström units of its parent. The false spectra not only occur in regions many hundred units from that occupied by the principal line, but also differs fundamentally from "ghosts" in other respects.

Mr. C. S. Peirce[2] has made a careful mathematical study of the subject and his paper also contains experimental data on the position of "ghosts" showing a good agreement between the theory and the observed facts. His treatment, however, deals only with "ghosts" occurring very near the parent line. Rowland[3] has

[1] Physical Review, I., 1901.

[2] American Journal of Math., II., 1879, p. 330.

[3] Rowland's Physical Papers, p. 525.

given a theory, the formulæ of which may be extended to the case of false lines occurring at a considerable distance from the parent. The author, however, has never been able to fit the positions or intensities of any of his observed false spectra into these formulæ in the form given by Rowland. In the case of most gratings this does not seem surprising since the false spectra are very numerous, of small intensity and with wave-lengths which bear no simple relation to one another. The error in ruling which produces them must be of a very complex nature and we cannot expect the phenomena to be brought readily under mathematical analysis. In some cases, however, an exact treatment should be possible, for with certain gratings some few of the false spectra are very much stronger than the others. Here it is fair to suppose that we have a comparatively simple error combined with a complicated one. Under the circumstances it seemed profitable to attempt to modify the ordinary treatment as given by Rowland.

A grating of N lines may, if $N = nm$, be considered as a grating of m groups, each consisting of n lines. The spectrum of the first order may be considered as the spectrum of the nth order of a grating of m groups. Each group is in itself a grating of n lines. The intensity I_n any point of a spectrum of a grating of n lines is known to be proportional to

$$A^2\left[\frac{\sin na}{\sin a}\right] \text{ where } a = e(\sin i - \sin r)\frac{\pi}{\lambda}$$

A^2 is the intensity of one line, which may be different in different directions, and e is the grating space or distance between two consecutive lines.

If we consider the grating of m groups the intensity at any point of its spectrum will be proportional to $I_n\left[\frac{\sin ma'}{\sin a'}\right]^2$ where $a' = na$. The 1st, 2d, 3d, $\cdots n-1$ order will vanish for any value of A because I_n vanishes for $a = \frac{\pi}{n}, \frac{2\pi}{n} \cdots \frac{(n-1)\pi}{n}$.

Now let us assume that in the ruling of n consecutive lines there is an irregularity, such that the grating of n lines which we take to be repeated m times is of itself an imperfect grating. Then I_n will

not vanish at all places where $a = \frac{\pi}{n}, \frac{2\pi}{n} \cdots \frac{(n-1)\pi}{n}$, and some of the first $n - 1$ orders of the grating of m groups will be visible. So far this is the ordinary theory of false lines.

Further, let us assume that the grating of n lines has a periodic error. To make the matter definite let us take this error as occurring every third line. That is to say every third line is slightly out of place while the other lines remain in their correct position. Then it is probable that I_n will have some appreciable value at $a = \pi/3$ and at $a = 2\pi/3$. If we take the error to be somewhat irregular the intensity I_n will spread to both sides of those positions where $a = \pi/3$ and $a = 2\pi/3$. The intensity of the light given by the whole spectrum for the wave-length λ will be appreciable for those values $a = \pi/n$, $2\pi/n \cdots [(n-1)\pi]/n$ which come near to the values $a = \pi/3$, $a = 2\pi/3$. Here n may be taken at pleasure. For the sake of a definite case let $n = 70$. Then I_n will have an appreciable value at $a = 23\pi/70$, $24\pi/70$, $46\pi/70$ and $47\pi/70$ for $\frac{23}{70}$ and $\frac{24}{70}$ are the nearest values to $\frac{1}{3}$; $\frac{46}{70}$ and $\frac{47}{70}$ are the nearest values to $\frac{2}{3}$. Moreover, since $\frac{1}{3}$ of 70 is 23.33, the 23d spectrum will be nearer this position than the 24th and therefore the stronger of the two. Similarly, as $\frac{2}{3}$ of 70 is 46.66, the 47th spectrum will be stronger than the 46th. Therefore, taking the number 70, the two spectra which are the stronger will be the lower of the first pair and the higher of the second.

If, then, we let $n = 70$ and consider the error to occur every third line in the grating, for each line in the spectrum there will be four repetitions between its normal position and the direct image of the slit. These repetitions correspond to the 23d, 24th, 46th and 47th order of the grating of m groups, the 70th order corresponding to the normal position.

This simple treatment of false spectra was suggested to the author by Professor Runge. The values used are those which seem most nearly to fit the case of the false lines obtained by the author from the grating called No. 1, and illustrated in a former article.

Before proceeding further to the numerical verification of this theory, it may serve to illuminate the matter if we place in contrast

with it the results which may be expected from the theory of Rowland.[1] The theory of Rowland is divisible into two parts, one dealing with the production of ordinary ghosts, the other part dealing with the production of lines at a considerable distance from the parent. It is this second part which could alone be expected to fit the case in hand. It does not do so, however, for it demands lines whose apparent wave-lengths bear simple ratios to the parent line. Professor Runge's theory shows the possibility of the total absence of lines at these positions indicated by Rowland, and it shows the probability of the formation of lines on either side of these positions at different distances and of an indicated relative intensity.

Thus in the present case the theory of Rowland might be made to call for lines at positions corresponding to $\frac{2}{3}$ and $\frac{1}{3}$ the wave-length of the parent line. The lines actually observed do not fulfil this condition but occur in flanking positions. For example, in the spectrum of magnesium, which is illustrated in Plate I, the line of wave-length 2790.8[2] which forms the most refrangible member of a characteristic group is seen to be reproduced four times. Two of these false spectra are in the region between wave-lengths 1,800 and 1,900 and two in the region between 900 and 1,000. It is to be noted that of the two groups near 1,800 the less refrangible is the stronger, while of the groups near 900 the more refrangible is the stronger. This is in accord with the theory, for if the two strong reproductions are considered to be the 47th and 23th spectra of the grating of m groups, the two weak reproductions are the 46th and 24th spectra, while the real line 2790.8 corresponds to the 70d spectra.

When, however, the wave-lengths as measured in the previous paper were compared with those calculated from the fractions $47/70 \times 2790.8$; $46/70 \times 2790.8$; $24/70 \times 2790.8$; $23/70 \times 2790.8$ the observed facts did not seem to agree with the theory as accurately as might be expected. It seemed worth while to remeasure the wave-lengths of the false spectra, in order to determine if the fault lay in the theory or in the observed values. The author was encouraged in this step by the interest which Professor Runge took

[1] Physical Papers, p. 535.

[2] Exner and Haschek, K. Akad. der Wis. in Wien, Bd. CVI., Abth, II., 1897.

in the matter. In fact the method employed in remeasurement was suggested by him.

The arrangement of the apparatus is shown in Fig. 1. Two slits, A and B, were placed upon the circle whose diameter was the radius of the concave grating. The grating itself was kept fixed in position and the normal to its surface fell midway between the two slits. By this method the image of A was formed at B. An arm carrying the plate holder C was pivoted at the center of the circle. The result of this plan was that the first spectrum obtained when A was used as source was shifted with respect to that obtained with B as source by a definite amount. The heights of the two slits were so arranged that the A spectrum fell directly over the B spectrum upon the photographic plate. The method of procedure was to illuminate A with the light from a magnesium spark and to place the plate holder C in such a position that a photograph of the false lines under investigation was obtained. Next B was illuminated by light from a spark between iron terminals and thus the standard iron spectrum was photographed under the false magnesium lines. To determine in Ångström units the amount by which the one spectrum was shifted with respect to the other, both A and B were illuminated with light from the iron spark and the relative position of two known lines was measured. As an example of the method, the false line, which by the theory should be the forty-seventh order of the grating of m groups, was compared with the line in the iron spectrum 3541.2[1] and found to have the relative position 3541.0. Next the line 2737.0[1] in spectrum A was compared with the line 4404.9[1] in spectrum B. The difference between them was .5 Ångström units. Thus the shift of spectrum A with respect to B was $(4404.9 - .5) - 2737 = 1667.4$, and the apparent wave-length of the false line was $3541 - 1667.4 = 1873.6$. In this way the apparent wave-lengths of the four false lines were determined. In order to check the accuracy of the method, slit B was moved toward

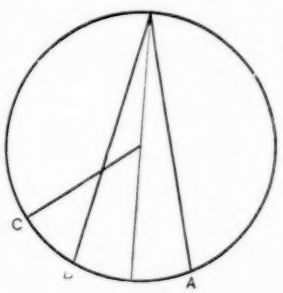

Fig. 1.

[1] Exner and Haschek, compare also Kayser and Runge Arc.

slit A and the grating was readjusted. In this way the shift of one spectrum with respect to the other was altered and the unknown spectra were compared with a new region of the iron spectrum. The following table gives some idea of the accuracy of the method and of the agreement between the observed and the calculated values.

Calculated.	First Observation.	Second Observation.
917.	917.0	916.8
956.8	956.7	956.4
1834.	1834.1	1833.9
1873.8	1873.7	1873.7

The method seems to be accurate to within .3 of an Ångström unit. The average difference between the observed and the calculated values is 0.15 units. Thus the difference between theory and practice is within the errors in observation.

It might seem that values different from $n = 70$ and a period of 3 would even better satisfy the conditions when substituted in the equations. This is not the case, as may be shown by trial. If there are to be but four reproductions and if the relative dispersions and intensities of these reproductions are to be explained, the values 70 and 3 give the result best in agreement with experiment.

Up to this point it has been the object of the discussion to contrast, in the light of these experiments, the theory of Professor Runge with that part of the theory as given by Rowland which would seem most obviously applicable to the case. This part of Rowland's theory was called "One line in m displaced;"[1] the other part of the theory which deals with "ghosts" came under the title "Periodic error."[2] A moment's consideration will show that the lines under discussion are not of this latter class.

In the case of "Simple periodic error" the position of any groove in the grating ruling is given by the equation $y = a_0 n + a_1 \sin(en)$. Thus the nth groove from a fixed line of reference is out of its true position by a term which varies as a sine function with period e; the maximum value of the displacement is of course a_1. Thus no groove in the grating surface is exactly in its proper place unless

[1] Physical Papers, p. 535.
[2] Physical Papers, p. 536.

$\sin(en) = 0$. The system of ghosts to which this form of error gives rise is characterized by the following properties:[1] Ghosts of any order must occur in pairs. Of a pair one lies to the right of the parent line, the other to the left. Ghosts of the second order must lie exactly twice as far from the real line as ghosts of the first order; ghosts of the third order three times as far.

The distance of a ghost of a given order from its parent line is a constant independent of the order of the spectrum in which the parent line is measured. These three properties are not in any way possessed by the lines under discussion. This, together with the fact that no numerical application of the theory of ghosts to the case in hand seems possible, excludes it from further consideration.

In short then, Professor Runge's explanation of the false spectra seems to fit the facts accurately. It is perfectly possible to extend the theory to even the more complex cases where there are more than four reproductions of every real line. The period of the error and the value of n may be taken at pleasure so that the treatment can be made to fit a great variety of cases. In practice, however, the errors of ruling in those gratings which give a great number of faint false spectra are too complex to make calculation profitable.

It may be of interest to remark that false spectra are not confined to concave diffraction gratings, but are to be found in the spectra produced by plane reflection gratings as well. The author has examined two instruments ruled upon speculum metal by Rowland's engine. In the experiment the light was collimated and brought to a focus by quartz lenses. In order to reduce the phenomena to the simplest possible form, a line in the visible blue spectrum of magnesium was separated out by a prism spectroscope and thrown upon the slit of the collimator. The camera was focused on the image of this line in the first spectrum. The first grating was ruled in 1883 and had 14,438 lines to the inch. The image of the line used appeared in its proper place in the first spectrum — = 4481.3 Ångström units — and was not accompanied by any ghosts of the common kind. That is to say, there was no doubling of the line, nor were there any faint reproductions very near it. In the region near wave-length 3,000, however, four sharp lines

[1] Rowland's Physical Papers, p. 519.

occurred, and again near wave-length 1,550, four more reproductions were present. Thus this grating produces eight false spectra of a lower order than the first, corresponding to the real line 4481.3. Besides these eight, numerous faint reproductions may be detected, but they are of extremely feeble intensity.

The second grating examined was ruled in 1887 and had also 14,438 lines to the inch. The spectrum obtained with it, however, was very different from that given by the first instrument. The first spectrum of the line 4481.3 was, as before, sharp and without ghosts, but the eight distinct false spectra were replaced by at least seventy reproductions of very feeble, but nearly equal intensity. These extended between positions corresponding to wave-lengths 2,000 and 900.

The results obtained with these two plane gratings are exactly similar in character to those obtained with the concave gratings called No. I. and No. II. and recorded in a previous paper. These gratings seem to belong to two types, the one in which the false spectra are all of nearly equal intensity and feeble, the other in which some few of the false spectra are many times more intense than the others. In the one case the grating gives a background of faint lines, in the other sharp, strong false spectra are present.

The author wishes to call attention to the plate which accompanies this article. It is from a concave grating of six-foot radius and shows the false lines whose positions have been discussed in this paper. The plate is taken directly from a negative by photographic process. The two groups at positions corresponding to wave-lengths 956 and 1834 are so faint in this reproduction as hardly to be visible. Their positions are indicated, however. The character and dispersions of the two stronger groups is well shown. All the lines in this plate are false.

The pairs of sharp lines in the immediate neighborhood of the characteristic groups to which the treatment has been confined, are reproductions of the real lines at 2936.8 and 2928.9. They form the 47th, 46th, 24th and 23d spectra of the system in which the real lines are the 70th spectra. The single line near the middle of the plate is the 23d false spectrum of the real line at 4481.3. The lines not far from it are the 23d false spectrum corresponding to

916.
956.
961.
1258
1472
1834.
1873
1966

the real lines 3838.5, 3832.5 and 3829.5. The 24th spectra of these lines are too feeble to reproduce. Their 46th and 47th spectra occur among real lines in the region between 3050 and 2500. The apparent wave-lengths of these false lines are marked upon the plate; the decimal place is omitted. The following table gives the exact measured apparent wave-lengths, the wave-lengths of the real lines of which the false spectra are the reproductions and the order of the false spectra.

Apparent Wave-lengths.	Wave-length of Parent Line.	Order of False Spectra.
916.9	2790.8	23d.
956.5	2790.8	24th.
961.8	2928.8	23d.
1258.4	3829.5	23d.
1472.8	4481.3	23d.
1834.0	2790.8	46th.
1873.7	2790.8	47th.
1966.5	2928.9	47th.

It is well to remember that this grating is not unique, but that most reflection gratings produce false spectra. It is in the extreme ultra-violet that these false lines are most easily seen, and it is in this region that they may be most readily taken for real lines. The lines may serve to show by their strength and sharpness the danger which they offer in spectroscopic work.

In conclusion, it may be well to repeat the chief result of this paper. False spectra differ fundamentally in character from the commonly observed "ghost." The former are due to a so-called periodic error in the grating ruling, an error which operates to displace every groove in the grating surface by an amount depending on a sine function of the position of the groove. It seems probable that the false spectra are due to an error of another type. Here the error operates to displace one, out of a given number of grooves, slightly, leaving the remainder in their proper positions. In order to make theory and the observed facts agree, this error must be considered somewhat irregular over the surface of the grating. While the theories proposed by C. S. Peirce and Rowland account in every way for the phenomenon of ghosts, they do not either qualitatively or quantitatively account for these false spectra,

whereas the theory proposed by Runge and given above explains the phenomena qualitatively and quantitatively. That is to say, it explains the production of lines far from the parent line, lying entirely on one side of it; it explains their relative intensity, and it explains very nearly indeed their exact position. The departure between the positions of these false spectra demanded by the theory and observed in the plates is never more than 0.4 Ångström unit. This is slightly greater than the errors of observation, but it is to be remembered that the measurements depend upon the wave-lengths of the parent group and of the comparison iron lines, both of which are borrowed data.

JEFFERSON PHYSICAL LABORATOY, HARVARD UNIVERSITY,
January, 1903.

ON THE RELATION OF THE DIELECTRIC CONSTANT OF WATER TO TEMPERATURE AND FREQUENCY.

By A. de Forest Palmer, Jr.

SOME observations made during the progress of an investigation[1] "On the Dielectric Constant of Dilute Electrolytic Solutions" led me to suspect that the variation of the dielectric constant of water with changes in temperature was greater than one would expect from the best published values of the temperature coefficient involved. The frequency of the electrical oscillations of my apparatus was considerably different from that employed in the determinations with which I was familiar and it occurred to me that this fact might explain the discrepancy. Accordingly the present inquiry was undertaken to determine whether the indicated difference was genuine or spurious. The results recorded below entirely corroborate the anticipated large value of the temperature coefficient for the frequency employed in my previous work and also show a value in good agreement with published results for frequencies of about sixty cycles per second.

The apparatus and general method of observation employed in this work have been very fully described in a previous communication;[2] the only modifications being the substitution of more accurate thermometers, the removal of the test electrodes used in determining changes in conductivity, and the provision of means for varying the temperature of one of the electrometers. The arrangement was essentially as follows: An electrical oscillator, of the Hertzian type, consisting of two Leyden jars with their outside coatings connected through a spark gap and their inside coatings connected to two long parallel copper wires was energized by a storage battery

[1] Palmer, Phys. Rev., 14, p. 38, 1902.

[2] Palmer, l. c., p. 44. The end of line 10, p. 46, of this description should read 1.5 mm. in place of 15 mm

and a large Ruhmkorff coil. Two quadrant electrometers A and B, of the cylindrical electrode and needle type, were connected in multiple between points on the two parallel wires equidistant from the jars. The needles were suspended from torsion heads by very fine platinum-rodium wires and carried concave mirrors so adjusted that they cast superimposed images, of an illuminated wire, on the central division of an observing scale, about two meters distant, when the needles were symmetrically situated with respect to the fixed electrodes.

Each electrometer was supplied with two mercury-in-glass thermometers, so placed that their long thin bulbs were just outside the spaces between the insulated and uninsulated quadrants and in line with the horizontal axis of the needle. These thermometers were graduated in fifths of a degree from zero to fifty degrees Centigrade and were very carefully calibrated by comparison with a normal thermometer, graduated in tenths of a degree, made by Max Kohl and supplied with a certificate from the Physikalisch-Technische Reichsanstalt.

Electrometer A was surrounded by a copper jacket through which water from the city mains was allowed to flow continually, and its temperature never varied during a series of observations by more than a few tenths of a degree Centigrade. A tin plate tank, of about ten liters capacity, surrounding electrometer B and containing cracked ice or water, served as a bath for regulating the temperature of the instrument. Any desired temperature between 0° C. and room temperature could easily be obtained by adding ice or warm water to the bath and stirring thoroughly till the thermometer readings became stationary. Then, on account of the great heat capacity of the bath and the small radiation constant of its bright tin surface, the change in temperature of the electrometer did not exceed two tenths of a degree per hour.

Both electrometers were filled with distilled water, conductivity 7×10^{-6} reciprocal ohms per centimeter cube, and complete series of observations between about 0°.3 C. and 16° C. were obtained with three different frequencies of the applied electrical field. The two higher frequencies were obtained with oscillators of the type above described, using jars of different capacity in the two cases,

and were respectively about 1×10^6 and 3×10^6 complete vibrations per second. For the lowest frequency the jars were removed and the parallel wires connected through a variable transformer to a source of alternating current of sixty cycles per second.

Before commencing a series of observations the temperature of electrometer A was allowed to become stationary at the temperature of the water supply of the laboratory and the bath surrounding electrometer B was brought to the lowest temperature for which observations were to be made and maintained constant sufficiently long for the temperature of the water in the electrometer to become uniform. The oscillator was then started and the images from the mirrors on the two needles brought to superposition on the central scale division by suitably turning the torsion heads. When this had been attained the current was turned off and after the images had come to rest their positions on the scale were noted and the readings of the thermometers recorded. The temperature of the bath was then raised a few degrees and the above operation repeated. This process was continued until the temperature of the bath had reached the room temperature and consistent results were always obtained. Above this point it was found impossible to maintain a sufficiently uniform and constant temperature, with the appliances at hand, to produce satisfactory results and, as time was not available for modifying the apparatus, the observations were discontinued. As indicating the uniformity of temperature attained in the electrometers it may be noted that the indications of the two thermometers situated some ten centimeters apart never differed by so much as one tenth degree Centigrade.

The method of obtaining the angular deflections δ_A and δ_B, of the two electrometers, from the scale readings of the images and the constants of the apparatus has been very fully discussed in my previous paper[3] and need not be recapitulated here. If R represent the ratio of the angular deflections, C the ratio of the constants of the electrometers, K the dielectric constant of the water in B and K' that of the water in A,

$$R = \frac{\delta_B}{\delta_A} = C\frac{K}{K'}.$$

[1] Palmer, l. c., p. 49.

When the temperature of A is maintained constant, K' is constant and any change in R, coincident with a change in the temperature t of B, must be due to a corresponding change in K, provided C is independent of t. In general this is not the case, but a calculation of the variation of C for the extreme temperature range of the observations, from the known dimensions and expansion coefficients of the materials from which the electrometers were made, showed that the error introduced by assuming C constant, would be much less than the probable errors of observation. Hence we may write

$$R_t = \frac{C}{K'} K_t.$$

Differentiating with respect to t and dividing by R_t

$$\frac{1}{R_t}\frac{\partial R_t}{\partial t} = \frac{1}{K_t}\frac{\partial K_t}{\partial t} = \beta_t.$$

Also

$$\frac{R_t}{R_{17}} = \frac{K_t}{K_{17}},$$

and if R is found to fulfil the linear relation

$$R_t = R_{17}\{1 + \beta_{17}(t-17)\}$$

K will satisfy the equation

$$K_t = K_{17}\{1 + \beta_{17}(t-17)\},$$

in which the numerical value of β_{17} is the same as in the preceding equation.

The observations were first reduced graphically on the assumption that K' was constant and the first approximation to β_{17} thus obtained was used to correct the observed values of R for the small changes in K' due to slight variation in the temperature of the water in electrometer A. The final values of β_{17} and the probable errors were calculated from the corrected values of R and t by the method of least squares.

The individual observations are sufficiently represented by the points marked on the chart, Fig. 1, where the ordinates correspond to corrected values of the ratio R and the abscissas to the tempera-

ture of the water in electrometer B in degrees Centigrade. Line 1 represents the observations with frequency sixty cycles per second, line 2, those with frequency 1×10^6, and line 3 those with frequency 3×10^6. The relative position of the three lines on the chart is without significance since the constant C/K' was different in the three series of observations owing to difference in the constant temperature of the water in electrometer A.

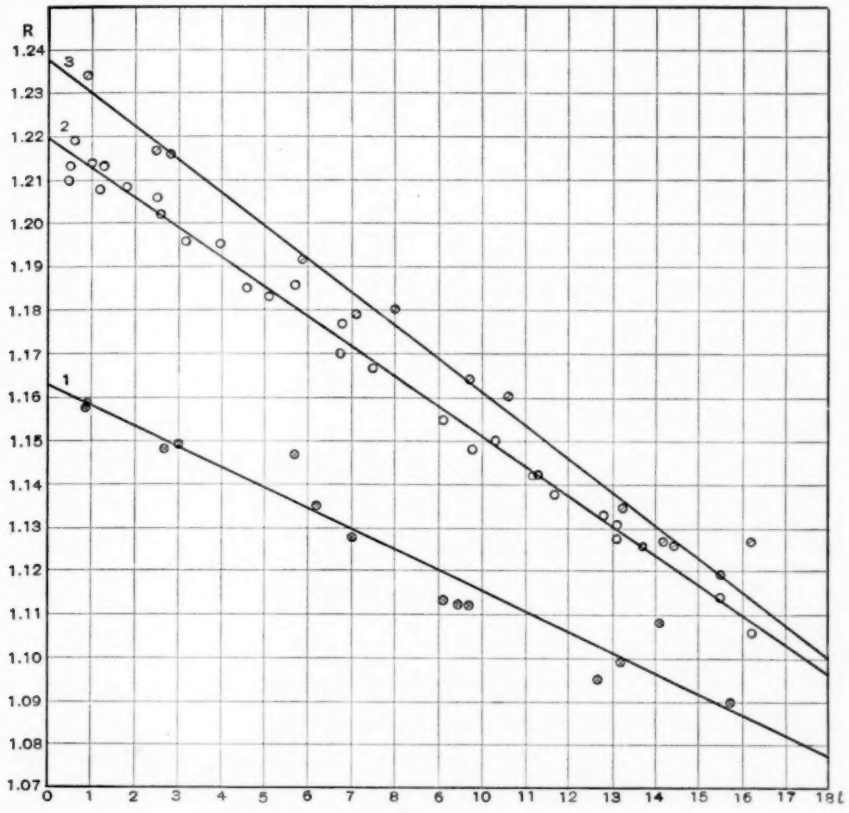

Fig. 1.

It should be noted that the scale of the plot is such that one division on the vertical axis corresponds to a change of less than one per cent. in the value of R and consequently that the observed points that lie farthest from the lines indicate observational errors of scarcely more than one per cent., while the great majority of the points represent values of R that are accurate within one or two

tenths per cent. The plot shows clearly that R and t are connected by the linear relation, within the errors of observation, between 0° C. and 17° C., and there is no indication of a maximum value of R at any point between these temperatures.

TABLE I.

Line.	K_{17}	β_{17}	Frequency.
1	1.082 ±.0023	−.0044 ±.00023	60
2	1.103 ±.0007	−.00624 ±.000066	1×10^6
3	1.107 ±.0012	−.0070 ±.00012	3×10^6

The calculated constants of the three lines with the corresponding probable errors are given in Table I. Taken by themselves they indicate a consistent increase in the numerical value of β_{17} with the frequency of the electrical field that cannot be due to the errors of observation. Electrometer methods, similar to the above, are, however, subject to three sources of constant errors that might, if sufficiently large, account for the observed result. These are polarization of the electrodes, variation of the constant C and inequality of the potential differences applied to the two instruments.

In a previous communication[1] I showed that the first of these errors was negligibly small, for the apparatus and method above described, when the frequency of the electrical field was 1×10^6 per second. Moreover in order to account for the observed increase in β_{17} it would be necessary to assume that the rate of change of the polarization with temperature increased with increasing frequency and in this case the observations might be expected to be more widely scattered for high than for low frequencies. But on inspection of Fig. 1 it is apparent that exactly the reverse is the case and that in all probability the observations at sixty cycles per second are more affected by polarization than the others. Yet the value of β_{17} derived from this series is in good agreement with the results obtained by other observers.

The constant C has been shown to be independent of the temperature, within the errors of observation, and it is obvious that a uniform continuous change in its value with lapse of time would

[1] Palmer, l. c., p. 55.

affect all the series alike and hence would not influence the relative values of β_{17}. Irregular variations would appear as errors of observation and are therefore included in the probable errors. A continually accelerated change is hardly to be expected and, since the observations at sixty cycles per second were made between the other two series, it is obvious that no such change did occur, for

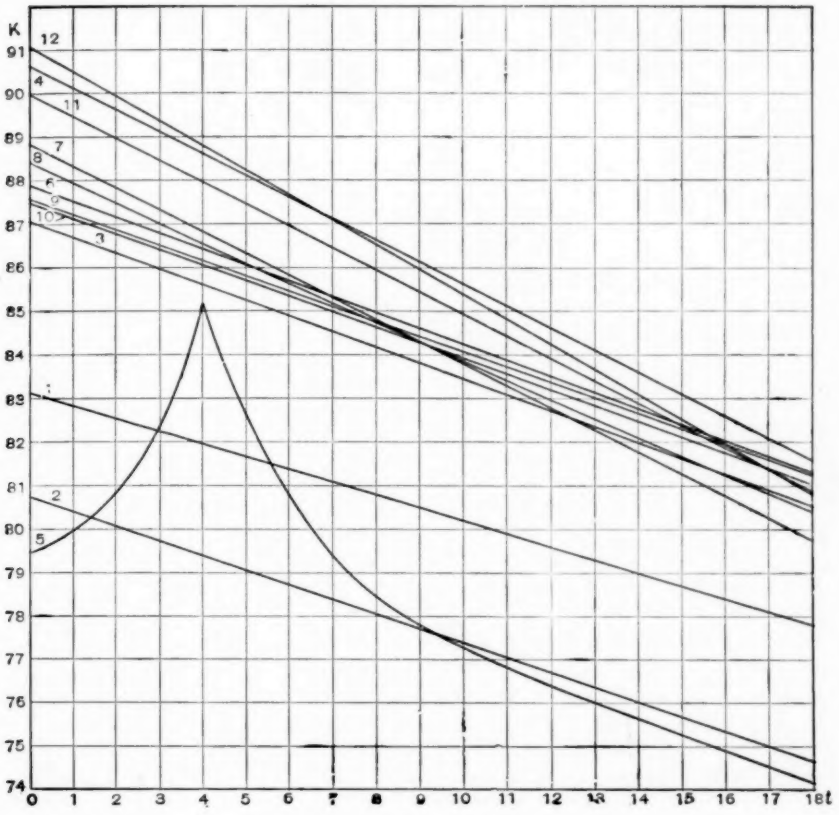

Fig. 2.

otherwise the value of β_{17} corresponding to frequency sixty would lie between the values at 1×10^6 and 3×10^6 instead of below both of them.

For the purpose of reducing the third source of error to a minimum the two electrometers were constructed as nearly alike as possible and the constant temperature of the water in A was chosen

about midway between the extreme temperatures of the water in B so that the capacity of the two instruments was never greatly different. The connecting wires to corresponding parts were as short as possible, of the same length and diameter, and symmetrically arranged, thus producing very small and nearly the same self induction in the two electrometer branches of the circuit. Under these conditions the effective potential differences at the terminals of the two instruments could not have been sufficiently different to produce sensible error provided their ratio was independent of the temperature. However, since the capacity and resistance of B decreased as the temperature increased, it is possible that all of the above results are affected by a residual error of this nature, but a calculation, from approximate values of the resistance, capacity and self induction of the two circuits and the variation of these quantities for the extreme temperature range, shows that this error is negligible in comparison with the errors of observation.

To facilitate comparison the results of previously published investigations of the variation of the dielectric constant of water with the temperature, so far as they have come to my notice, are collected in Table II. and graphically represented on the chart, Fig. 2, where values of K are plotted as ordinates and values of t as abscissas. The numbers in the first column of the table correspond to those on the lines of the chart. The second column gives the authors of the determinations, the third the values of the dielectric

TABLE II.

No.	Observer.	K_{17}	$-\beta_{17} \times 10^5$	Frequency.	Temperature.	Date.
1	Rosa.	78.10	375	50	3°–31°	1891
2	Cohn.	75.00	445	1×10^8	9°.5–35°.3	1892
3	Heerwagen.	80.88	448	42–85	4°.7–26°	1893
4	Franke.	82.10	614	40	2°.6–25°.3	1893
5	Thwing.	74.70	626	1.5×10^7	6°–20°	1894
6	Drude.	81.67	451	4×10^8	0°–25°.8	1896
7	Ratz.	80.25	632		4°–30°	1896
8	Abegg.	80.84	526			1897
9	Coolidge.	81.60	432	2×10^8	3°.5–24°.7	1899
10	Palmer.	81.40	440	60	0°–16°	1903
11	Palmer.	81.40	624	1×10^6	0°–16°	1903
12	Palmer.	81.40	700	3×10^6	0°–16°	1903

constant at 17° C. (K_{17}), the fourth the values of $\beta_{17} = 1/K\ \partial K/\partial t$ at 17° C., the fifth the frequency of the electrical field employed in making the determinations, the sixth the range of temperature for which the linear relation holds or the total range of the observations, and the seventh the year in which the work was published. The values of β_{17} attributed to Thwing and Abegg were calculated by the author and represent the straight lines nearest to their results, but since neither of these observers found a linear relation betweeu K and t the values thus obtained must be regarded as rough approximations.

Rosa's[1] observations were made with an electrometer of the attracted disk type. The source of electromotive force was a gravity battery and the direction of the current was reversed about fifty times per second by a mechanical commutator. Potential differences were measured by a Weston voltmeter connected to the battery side of the commutator.

Cohn[2] generated a system of stationary electrical waves along two parallel wires and determined the ratio of the wave-lengths on parts of the wires surrounded by air and water respectively. The refractive index n thus found was reduced to dielectric constant K by Maxwell's relation $K = n$.[2]

Heerwagen[3] used two quadrant electrometers placed one above the other with their needles on the same suspension and determined the ratio of the potential differences that would reduce the deflection to zero when applied to the two parts of the instrument in opposite directions.

Franke[4] observed the deflections of two quadrant electrometers connected in multiple between the earth and one terminal of a Kohlrausch adjustable condenser. The other terminal of the condenser was connected to earth through the secondary of an induction coil the primary circuit of which was interrupted about forty times per second.

Thwing's[5] method was based on the principle of electrical reso-

[1] E. B. Rosa, Phil. Mag. (5), 31, p. 188, 1891.
[2] E. Cohn, Wied. Ann., 45, p. 376, 1892.
[3] F. Heerwagen, Wied. Ann., 49, p. 272, 1893.
[4] A. Franke, Wied. Ann., 50, p. 163, 1893.
[5] C. B. Thwing, PHYS. REV., 2, p. 35, 1895; Zeit. Phys. Chem., 14, p. 286, 1894.

nance. Two neighboring circuits of constant self-induction but variable capacity were adjusted to unison, by a parallel-plate adjustable condenser in one of them, while a cylindrical condenser of fixed dimensions was included in the other. The capacity of the fixed condenser was thus determined first with air as dielectric and then with water at various temperatures. The frequency of the electrical oscillations of the system is not stated in the published description and I take pleasure in expressing my thanks to Professor Thwing for his courtesy in calculating the same for me with the result given in the above table.

Drude[1] adopted a method similar to that used by Cohn and developed it to a high degree of accuracy and convenience.

Ratz[2] employed Nernst's[3] bridge method and his results are relative to Nernst's value $K = 79.6$ at 18°.1 C. The frequency of the alternating current used is not stated.

Abegg's[4] results were calculated with the formula

$$K = 372\, E^{-\frac{T}{190}}$$

in which T is the absolute temperature, E the base of the Napierian logarithm, and the constant 372 represents the "imaginary" dielectric constant of water at absolute zero. This formula was derived, with the aid of the rule for mixtures, from two series of observations, by Nernst's method, extending over a temperature range — 86° to 0° C. One of the series was carried out with ethyl-alcohol and the other with a mixture of ethyl-alcohol and water of known proportions.

Coolidge[5] inserted a water condenser in an oscillating system connected to two parallel wires and determined the changes in wavelength produced by changes in the temperature of the water. The absolute value of his results is based on Drude's value at 19° C.

In order to include the results of my own observations in Fig. 2 I have adopted 81.4 as the dielectric constant of water at 17° C. and drawn the lines 10, 11 and 12 through the corresponding point

[1] P. Drude, Wied. Ann., 59, p. 17, 1896.
[2] F. Ratz, Zeit. Phys. Chem., 19, p. 109, 1896.
[3] W. Nernst, Zeit. Phys. Chem., 14, p. 622, 1894.
[4] R. Abegg, Wied. Ann., 60, p. 54, 1897; Wied. Ann., 62, p. 257, 1897.
[5] W. D. Coolidge, Wied. Ann., 69, p. 125, 1899.

on the diagram with the inclinations required by the values of B_{17} given in Table I. The value 81.4 for K_{17} is the mean of the independent determinations given in Table III. and is probably accurate to within less than one per cent.

TABLE III.

Observer.	K_t	t	K_{17}
Heerwagen.[1]	80.88	17°	80.88
Franke.[2]	82.10	17	82.10
Drude.[3]	81.76	17	81.76
Nernst.[4]	79.6	18.1	80.00
Tereschin.[5]	83.8	13.5	82.50
Turner.[6]	81.1	18	81.50

The first column of the table gives the author of the determination, the second the value of the dielectric constant K found at the temperature stated under t, and the fourth the value of K_{17} calculated from K, when necessary, with the value $-.0044$ for β_{17}.

In drawing the three lines through the same point on the chart it is not intended to intimate that the dielectric constant of water is the same for all frequencies at 17° C., for this is probably not the case. However, sufficient data is not available to determine the relative values of K_{17} for the frequencies in question and the relation between β_{17} and the frequency is more clearly shown by adopting a common point for the three graphs.

The close agreement of the values of β_{17} corresponding to frequencies of less than one hundred cycles per second, obtained by Rosa, Heerwagen and the author, with the values corresponding to frequencies of the order 10^8 per second, found by Cohn, Drude and Coolidge, is strong evidence that β_{17} is independent of the frequency. On the other hand all determinations with frequencies between these limits have resulted in values of β_{17} that increase numerically with the frequency. Hence taken as a whole the results given in Table

[1] Heerwagen, l. c.
[2] Franke, l. c.
[3] Drude, l. c.
[4] Nernst, l. c.
[5] S. Tereschin, Wied. Ann., 36, p. 792, 1889.
[6] B. B. Turner, Zeit. Phys. Chem., 35, p. 385, 1901.

II. are inconsistent unless we assume that β_{17} first increases to a maximum and then decreases to its initial value as the frequency increases from about 10^2 to about 10^8 per second. The data in hand are obviously insufficient to establish this proposition and the only definite conclusions that can be drawn from it are that β_{17} is not independent of the frequency and that further investigation is necessary to establish the exact relation between these quantities.

BROWN UNIVERSITY,
January 19, 1903.

THE INFRA-RED EMISSION SPECTRUM OF THE MERCURY ARC.

By W. W. Coblentz and W. C. Geer.

THE present investigation of the radiation from the mercury arc was undertaken to account for the high efficiency[1] of the Arons lamp.

The spectrum was produced by means of a mirror spectrometer, and a rock salt prism, while a Nichols radiometer was used to measure the distribution of energy. The whole is shown in Fig. 1 in which N is the source, S the shutter, P the rock salt prism and R the radiometer. A full description of the adjustment and calibration of the apparatus is given elsewhere[2] and need not be mentioned here.

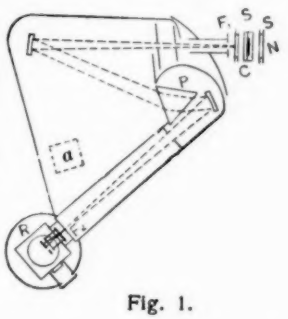

Fig. 1.

The Mercury Arc.

The arc was formed in a vacuum tube which was a modification of that first described by Arons.[3] The vertex of the arc was used as a source of radiation. For this purpose a side tube, having a window of fluorite or rock salt, was placed at right angles to the plane of the arc.

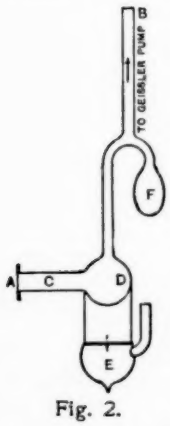

Fig. 2.

The side elevation is shown in Fig. 2. The diameter of C was 1 cm., that of D 2.5 cm., with the other parts in proportion. Throughout the work the lamp was connected to a Geissler pump and when in use the stopcock at B was closed. The whole was enclosed in a tin box containing water with the side tube, C, projecting through a water-tight sleeve. A fluorite window was at A for wave-

[1] Geer, Physical Review, Vol. XVI., No. 2, 1903.

[2] Coblentz, Physical Review, Vol. XVI., Nos. 1 and 2, 1903.

[3] Arons, Wied. Ann., 47, 767, 1892.

lengths up to 6 μ, while a window of rock salt was employed from 6 to 9 μ.

The mercury was purified by running it through a separatory funnel containing mercury, on the surface of which was a layer of mercurous sulphate and concentrated sulphuric acid. The mercury treated in this way was some that had been standing in contact with the cleaning agent for several weeks. By this means it was freed from moisture and metallic impurities. It left no weighable residue upon evaporation.

During the exhaustion the mercury was continually flowed from one leg of the lamp to the other to free it from all traces of air. Throughout the investigation the lamp was pumped out at frequent intervals in order to be certain that the vacuum was maintained. On starting the arc the vacuum was always less than 0.03 mm.

A direct current of six ampères was used throughout the work. The water in the tank varied from 50° to 80°. It was allowed to become warm since it produced a larger arc. Larger currents were not used for fear of breaking the lamp.

CURVES AND RESULTS.

It was found that the energy radiated consists of a series of emission bands at 1 μ and 5 μ with a slight indication of a band at 3 μ. Nowhere in the spectrum was the intensity of the radiation from the arc very great. This indicates a low temperature like that of gases in vacuum tubes,[1] although Arons[2] has computed a value of several thousand degrees.

The distribution of the maxima is best shown by the curves in Fig. 3. For the region at 1 μ the mean of several readings has been plotted, while beyond 4 μ individual readings are given.

In Table I. a typical set of readings is given for the region from $\lambda = 0.92$ to $\lambda = 2.0\,\mu$. It shows that the variation in the individual

[1] Salisbury first observed the low temperature of such gases. Phil. Mag. (4), 45, p. 241, 1873.
E. Wiedemann, Calorimeter, Wied. Ann., 6, p. 298, 1878; 10, p. 202, 1880.
Paalzow Weesen, Wied. Ann., 56, p. 276, 1895.
Warburg, Theory, Wied. Ann., 54, p. 265, 1895.
Wood, Bolometer, Wied. Ann., 59, p. 238, 1896.

[2] Arons, Wied. Ann., 58, 1896.

readings is not great, when one considers the smallness of the deflections.

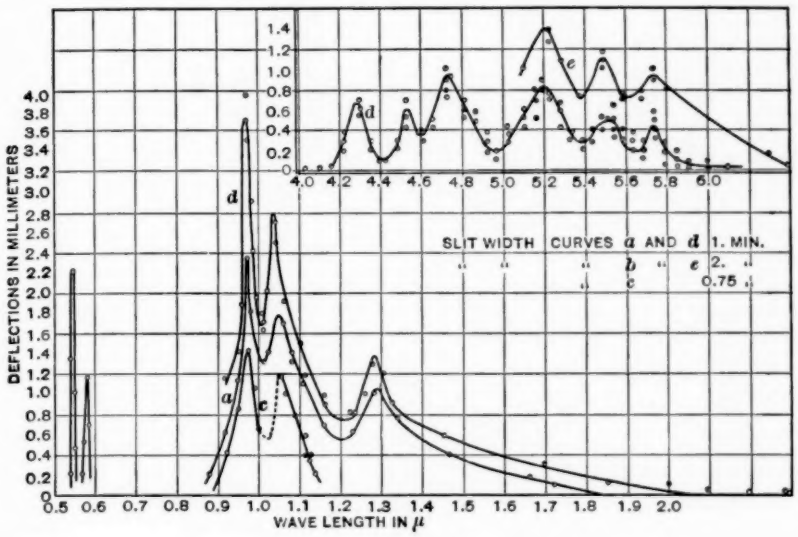

Fig. 3.

TABLE I.

Deflections in Millimeters. Wave-lengths in μ.

λ	.92	.95	.98	1.01	1.02	1.06	1.08	1.10	1.16	1.23	1.28	1.34	1.46	1.72	2.03
Deflections.	0.5	0.9	1.7	1.5	1.5	1.7	1.3	1.2	0.8	0.7	1.0	0.8	.03	00	00
	0.4	1.4	2.0	1.2	1.4	1.7	1.4	1.3	0.6	0.5	1.1	0.9	.05	00	00
	0.6	1.0	1.8	1.1	1.3	1.8		1.2			1.0			.02	00
	0.8		1.8	1.4		1.6		1.1			0.8				
Mean,	0.5	1.1	1.8	1.3	1.4	1.7	1.4	1.2	0.7	0.6	1.0	0.9	.04	00	00

λ	.92	.95	.96	.97	.98	.995	1.01	1.02	1.04	1.06	1.16	1.26	1.28	1.32	1.34
Deflections in mm.	1.2	1.4	1.6	3.8	3.0	1.9	1.6	2.0	2.2	1.6	0.8	0.8	1.1	0.9	0.7
	1.1		1.9	3.5	2.8	2.0	1.8		2.4	1.7	1.0	0.5	1.0	0.9	0.8
				4.2					2.7	1.9			1.3		
									2.5				1.3		
Mean,	1.1	1.4	1.8	3.7	2.9	2.0	1.7	2.0	2.5	1.7	0.9	0.6	1.2	0.9	0.7

The difficulties in observing the deflections were extreme on account of the weakness of the radiation. These small deflections are not due to lack of sensitiveness of the radiometer, for, under like

conditions, a cylindrical acetylene flame gave a deflection of 50 cm. at the maximum part of its spectrum, while the CO_2 emission band of a bunsen acetylene burner at 4.4 μ threw the deflection clear off the scale.

Although the deflections were small they were trustworthy. It should be remembered that the radiometer at the sensitiveness used was unusually stable. The mirror suspension was not the lightest, so that earth tremors rarely caused annoyance. No readings were made when such vibrations were noticeable. The period of the radiometer was about thirty seconds. In order to reduce the errors due to temperature changes it was necessary to shorten the period at a sacrifice of the sensitiveness of the instrument. The radiometer was packed in wool, in a tin box, and the zero shift, due to changes of temperature, for single readings was generally only 0.1 to 0.2 mm., while often it was not to be noticed at all. The whole apparatus stood in an inner room and the deflections were observed through a hole in the wall. When there was no disturbance in the room the zero shift was always extremely small. On exceptional days—not for this work, however—the zero shift could not be detected during ten minutes, on actual count, while in four hours it amounted to only 1.6 cm.

In the first exploration (slit 1 mm. in width), up to 6 μ, the apparatus was not so sensitive and no radiation from the hot walls of the tube could be detected. But when the fluorite window was replaced by one of rocksalt, and an increased sensitiveness of the radiometer was combined with a slit of 2 mm. width, the hot glass radiation was perceptible beyond 5 μ. Consequently, for each setting of the spectrometer the radiation from the hot glass was measured and deducted. For the latter measurement the shutter at the window was raised at the instant that the arc was extinguished. It was found that beyond 6 μ up to 9 μ, which was so far as the exploration extended, the average deflections for the hot glass were as large as those due to the arc.

The spectrum was explored at every minute of the spectrometer circle up to 9 μ, while in certain regions readings were made at every 20″. Consequently, this required several days and several maxima of the curves were tested each day in order to determine

their relative heights. This variation of height, due to the changes in the sensitiveness of the instrument, is shown in Fig. 3. The best values for the relative heights is shown in the curve *b*. In Fig. 4 the complete curve is given. The deposition of mercury on the window was one source of annoyance and at times vitiated the readings. On three different days observations were made on the region from 2 μ to 4 μ, but no radiation could be detected except at about 3 μ where there was a slight deflection at times. This is of interest in what follows.

The reflecting effect of the glass walls is not known. Since glass becomes opaque at 3 μ it will be noticed that all the energy of

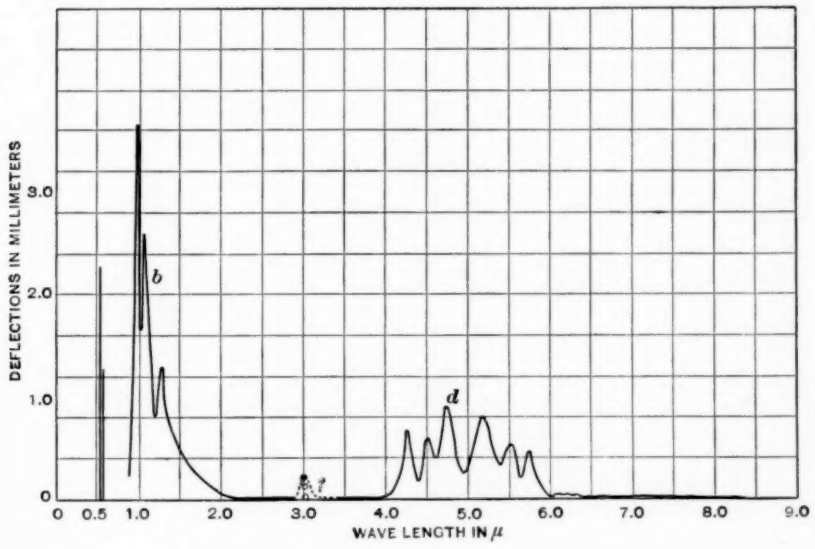

Fig. 4.

greater wave-length is absorbed by the glass in a lamp of the form described by Arons. Thus the apparent radiant efficiency of the arc would be greater than the true efficiency. This accounts in part for the unusually high values found in the previous investigation.[1]

The width of the spectrum covered by the radiometer vane at 1 μ was about .15 μ. The error at 1 μ is less than .01 μ while at 4 μ it s perhaps .03 μ.

[1] Geer, l. c.

ADDENDUM ON SPECTRAL SERIES.

After the work had been completed, the senior writer repeated some of the observations to find the bearing of the emission maxima on laws for spectral series. Also to learn whether another line exists between 1.06 and 1.12 μ where the curve is very asymmetrical. It was found that the mean of a great many readings was very nearly the same for $\lambda = 1.08$ and $1.10\,\mu$, and if another line exists it is very weak.

From their work on the elements of the second group of Mendeleeff's classification, viz., Mg, Ca, Sr, Ba; and Cd, Zn, Hg, Kayser and Runge[1] have found that there are groups of lines, triplets, distributed throughout the visible spectrum, whose position can be expressed by an empirical formula of the form

$$1/\lambda = A + Bn^{-2} + Cn^{-4}$$

where $1/\lambda$ is a function of the frequency and n represents the successive integral numbers. They have also found that the difference between the values of $1/\lambda$ for the members of any triplet is constant for any given element. In the case of mercury this difference is

$$v_1 = \begin{cases} (4584.6) \\ 4630 \end{cases}$$

$$v_2 = 1760.0.$$

By means of their formula, for $n = 3$, they predicted a triplet at $\lambda = .9497\,\mu$, $.6595\,\mu$, $.5906\,\mu$. But they add that these lines may lie still farther toward the infra-red. This follows from the fact that the wave number, $1/\lambda$ in negative powers of n^2 forms a rapidly converging series, and three terms were sufficient for their work. Now the triplet, $n = 3$, of the first subordinate series, falls in the infra-red and the computed values of λ are obtained through wide extrapolation. They add that the formulæ require more terms with smaller powers of n, when n is less than 3. Hence they expected to find that for cæsium the predicted infra-red lines would be farther out by $.02\,\mu$.

From the curves in Fig. 3 it will be seen that maxima occur at .97, 1.045, 1.285, 4.28, 4.53, 4.73, 5.20, 5.50 and $5.73\,\mu$. It

[1] Kayser & Runge, Die Specten der Elemente, IV.; Wied. Ann., 41, 302, 1890.

will be observed that the one at .97 μ agrees remarkably well with the predicted value .9497 μ, especially when one remembers that Kayser and Runge expected the latter value to be larger. The fact that the radiometer failed to detect the other two lines is no reason for considering that this is not the third. Still more interesting is the fact that the difference between $1/\lambda$ for the maxima at 1.045 μ and 1.285 μ ($v_2 = 1787$) are unusually close to those in the visible spectrum, that is, they appear to belong to another triplet, of which the third component lies at 3.05 μ. The latter is obtained by computation, using the value $v_1 = 4630$. Since at 3.0 μ the radiometer showed slight deflections at times which were recorded as questionable, and since in all other parts of the spectrum from 2 to 4 μ no such effect could be detected, one is led to believe that the deflections observed as 3 μ were real. The great variation in the intensity of these lines may be due, in part, to the fact that the slit subtends different angles in the two regions, and that the suspected line at 3 μ is isolated while the others occur in a group, each one of which is influenced by those adjoining it.

In Table II. are given the observed maxima and the products obtained by multiplying each one by the arbitrary factor 4.4. According to Kayser and Runge the first, second and third components of a sharp or diffuse series of triplets form, in each element, a line series. Whether the maxima at 4 to 6 μ are thus related to those at 1 μ has not been determined, but the coincidence, when the arbitrary factor 4.4 is used, is very striking.

TABLE II.

A°. U. from Kayser and Runge.		A°. U. Observed.	$10^8 \div \lambda$.	Difference.
$\lambda = 3007.02$	$v_1 = 4584.6$	$\lambda = (30500\ ?)$		
2642.70		12850	7783	$v_2 = 1787$
2524.80	$v_2 = 1767.0$	10450	9570	
3680.74				
3144.61	$v_1 = 4631.8$			

Maxima.	Maxima × 4.4.	Observed.
.97	4.27	4.28
1.04	4.56	4.53
1.29	5.68	5.73

The unavoidable errors in drawing the curves account, in part, for the variations between the predicted and the actual positions of the maxima. Since most of the curves were drawn prior to the consideration of their bearing on the question of spectral series the position of the maxima is not biased by the latter. An inspection of Fig. 2 shows that, through the few points observed, curves can be drawn which have different trends, especially when they are asymmetrical. For this region a prism of greater dispersing power, *e. g.*, carbon disulphide, would have increased the accuracy of the work.

CONCLUSION.

From the foregoing investigation it is seen that the infra-red spectrum of the mercury arc comprises several well-defined bands with perfectly definite maxima. These maxima occur at the following wave-lengths: 0.97, 1.045, 1.285, 4.28, 4.53, 4.73, 5.20, 5.50 and 5.73 μ.

The presence of the bands of wave-lengths greater than 4 μ indicates that the true radiant efficiency of the arc is lower than that previously found.

The maxima of the curves at .97, 1.045 and 1.285 μ follow quite closely the law of spectral series as developed by Kayser and Runge

CORNELL UNIVERSITY,
November, 1902.

THE RELATION OF IONIZATION TO NUCLEATION IN THE CASE OF PHOSPHORUS.

By C. Barus.

1. *Introductory.* — The opinion was expressed in my earlier papers, that wherever there is intense ionization, there one may also expect to find active nucleation; for it is hardly probable that a group of ions neutral as a whole can ultimately escape combination with the medium in which they are suspended. If these combinations occur in the presence of water vapor and particularly in a saturated atmosphere, the nuclei due to solution are the result. When the nuclei are produced from dilute solutions by shaking, there is evaporation of the fog particle to the nuclear diameter; when the solute is produced by any kind of radiation or emanation, each trace of solute grows in bulk by absorbing water to the nuclear stage. In case of an intense emanation like that from phosphorus, this process may actually continue until a visible cloud is produced and the nuclei attain the size of fog particles. Slow spontaneous condensation is induced even without exhaustion, while the fog on sudden cooling in the presence of water vapor is correspondingly intense.

2. If the original emanation, highly ionized, though neutral as a whole, is put through the process of condensation, then if the negative ions are more efficient as condensation nuclei than the positive ions, the nuclei after condensation or even after remaining in a saturated atmosphere, should become *continually more positive* — assuming that a greater number of negative ions are removed by condensation.

The investigation would therefore consist in testing the ionization immediately coming from phosphorus as to its power in dissipating positive and negative charges, and to compare these results with the degree of ionization after the emanation has produced condensation. In other words, it is to be ascertained whether the nuclei after a succession of condensations become continually more positive.

The results to be discussed in the following paragraphs have made this apparently straightforward investigation of little value: for before the emanation has been made available for condensation, scarcely 3 per cent. of the original ionization is left. The residue is then so small that a decision of a possible excess of positive or negative ionization is difficult, because the whole is now of the same order as the normal leakage of the electrometer. Meanwhile the nucleation or condensational activity, so far as discernible, has suffered no appreciable decline.

In fact, the decision as to whether the positive or negative ionization is in excess is now of very secondary interest, for the nuclei introduced into the condensation chamber have already lost all but a trifle of their original charges. All the successive and even the initial condensations thus virtually proceed without electrification.

The initial intense ionization nearly vanishes even in a moderately dry atmosphere. Indeed, it is hard to understand how a neutral, intensely ionized emanation can be produced from a body like phosphorus. It appears to me that the emanation is a molecular body which is stable in the presence of an excess of phosphorus, *i. e.*, at the surface, but which becomes unstable and breaks to pieces in presence of an excess of air, on leaving the phosphorus. The observed ionization is the accompaniment of this dissociation. If the ions were produced by phosphorus directly one would expect that they would be either positive or negative but not neutral.

3. *Water Nuclei.* — After finishing the work with phosphorus, correlative experiments with water nuclei were undertaken. It was found necessary, however, to produce them in greater number than is possible by mere shaking, to obtain marked effects. Hence jets were resorted to and studied in some detail, as has been shown elsewhere.[1] The results obtained, though closely resembling the phosphorus data in the main, differed from them inasmuch as the currents above a certain potential difference were constant and independent of the electromotive force of the condenser, while the ionization or charge is usually not neutral as a whole. Nucleation again remained equally effective after the ionization had all but vanished in the speedy way observed for phosphorus.

[1] Cf. Am. Journal of Science (4), XV., pp. 105–120, 1903.

4. *Comparison of the Steam Jet and the Condensation Chamber.*— A digression may here be made relative to the indications of the colors of the steam jet and of the coronal phenomena, in relation to the number of nuclei concerned. The usual and strong response of the steam jet is for axial blues and greens as far as the purples of the second order. These are already too weak to be of effective service for measurement. But at this stage of smallness of fog particle, the coronal display has but begun. The strong blues of the axial colors correspond to the diffuse gray fogs of the condensation chamber out of which the coronas are gradually evoked when the number of particles[1] has sufficiently diminished.

The two instruments are thus in a measure supplementary; the condensation chamber gives intense evidence of the presence of nuclei long after the steam jet would imply their absence. It is for this reason that ordinary smokes like sal ammoniac do not affect the steam jet where a number of nuclei exceeding a certain lower limit is necessary. The latter again is particularly active for those intense and fresh nucleations which produce the browns and yellows of the first order, implying a degree of abundance or fineness of nucleation which it is impossible to produce in the condensation chamber at all.

5. *Decay and Absorption.* — To account for the rapid diminution of the number of nuclei in the phosphorus emanation in the lapse of time, two hypotheses are prominent. With finely divided and in so far highly potentialized matter (particularly when ionized positively and negatively) combinations of nuclei may occur to the detriment of the number of independent nuclei. Such a decrease would take place as the square of the number. On the other hand it is equally probable that the initial and very small nuclei are in rapid motion much like molecules, and that the loss takes place by absorption or arrest at the walls of the vessel. In my memoir on the subject I included both hypotheses in the computation; but finding that the phenomena for phosphorus could be adequately explained by the latter, I ignored all spontaneous decay. Though this policy would not be generally admissible, it is unlikely that nuclei can vanish initially at the same rapid rate as the ionization.

[1] Phil. Mag. (6), IV., p. 24, 1902; cf. Structure of the Nucleus, chapter III.

Indeed the evidence already instanced shows that it does not. In case of water nuclei which are much the more sparsely distributed, the original number of nuclei can be proved by coronas to have varied but little, neither increasing nor decreasing in the short time in which the ionization falls off to a few per cent. Hence the nuclei must be regarded as parting with their charges more rapidly than they are themselves absorbed in the lapse of time, and one will have to distinguish between the velocity of the uncharged and of the charged nucleus in the electric field, the latter being incremented by the electric forces.

6. *Apparatus.* — The apparatus used in the present experiments was capable of a great number of variations. The essential purpose is to enable the observer either to introduce phosphorus emanation at once into the electrical condenser, or else to introduce it after it has been saturated with water, suddenly cooled or otherwise treated.

The parts of the train of apparatus are the large copper Mariotte flask, with a supply of water sufficient for aspiration; the condensation chamber or receiver, used both for producing coronas and for the aspiration and storage of air laden with phosphorus nuclei; the vacuum reservoir, the phosphorus ionizer, the tubular electrical condenser and the electrometer. An accessory desiccator of the tower form may be inserted on the way when dry air is needed.

The vacuum reservoir is connected through a stopcock with a suction pump, with the atmosphere and (by wide tubing) with the condensation chamber. It carries a vacuum gauge.

The receiver is connected by a stopcock with a cotton filter, with the phosphorus ionizer (where the tall desiccator may be inserted), with the vacuum reservoir and also carries a vacuum gauge. The receiver is further joined by stopcocks with the Mariotte flask for aspiration, and is graduated in liters on its side. It holds about ten liters.

The ionizer is a large **U** tube containing calcic chloride for desiccation, kept in place by loose cotton plugs. One shank is nearly empty, and carries thin pellets of phosphorus between strips of wire gauze.

The condenser is tubular, 2.10 and .64 cm. in diameter and 50

cm. long, with the outer mantle permanently put to earth. The core is a brass rod, supported on hard rubber insulators about 15 cm. long and at a distance of 10 cm. from the end of the tube. This rod is highly charged by a storage battery, and its leakage found from the electrometer, one pair of quadrants of which are in connection with the rod and the other pair put to earth. A commutator enables the observer to use either the positive or the negative pole of the storage battery for charging the system.

The electrometer was specially built for the present purposes and the needle was kept charged by a water battery of 48 volts, one pole of which was earthed. The suspension is a silk bifilar moistened by a dilute solution of any hygroscopic salt, and the battery charge is conveyed through the fibers. The quadrants are supported on hard-rubber insulators 10 cm. long. Difficulties were encountered in using this apparatus as will appear elsewhere.

7. *Manipulation.* — On raising the Mariotte flask, and opening appropriate stopcocks, the emanation passes directly from the ionizer into the condenser and its ionization may be measured. A tower desiccator is here to be inserted ahead of the ionizer to dry the air.

On lowering the Mariotte flask, removing the desiccator, and reversing the ionizer, the emanation passes into the receiver. Here its nucleation may be tested by condensation, and it may therefore be introduced into the condenser, at once or after a number of condensations. The nucleation may also be stored in a dry vessel and subsequently transferred from it into the condenser.

Finally the phosphorus ionizer and desiccator may be quite removed and replaced with a pipe connection adjusted for spraying. Hydrant water passing under high pressure reaches a jet placed suitably within the receiver. The water nuclei thus producable may be tested either by coronas or electrically by passing them into the condenser.

Ionization of Phosphorus Nuclei Collected Over Water.

8. *Data.* — The current through the condenser follows a law similar to Ohm's. The constant appropriate for the comparison of the data may therefore be computed logarithmically. If C is the

capacity of the apparatus in parallel, E the potential of the condenser, i the radial electric current through it, R its ohmic resistance for the given medium, s the deflection at the electrometer,

$(dE/dt)/E = (ds/dt)/s = 1/CR$, or $d(\log s)/dt = .434/CR = a$,

where common logarithms are used and a is the constant sought. Thus a varies directly with the conduction of the ionized medium traversing the condenser.

TABLE I.

Conduction of room air aspirated over phosphorus, directly or indirectly into condenser.

	Remarks.	$a \times 10^2$
I.	Insulation of electrometer (morning).	7
II.	" " " (afternoon).	10
V.	Slow current (liter/min.) of phosphorus nuclei in saturated moist air entering condenser.	8
VI.	Do., but faster current (10 liter/min.).	14–16
VII.	Phosphorus nuclei enter condenser by diffusion.	8
VIII.	Do., slowly blown in with moist air.	7
IX.	Phosphorus nuclei enter condenser *directly* from ionizer. Fast current of moist air.	320
XI.	Do., slower current.	200
XII.	Do., slow air current but fresher phosphorus.	320
XIII.	Ionized air current stopped; observations immediately after.	54
XIV.	Do., after a few minutes.	14
XV.	Insulation finally.	8

Cases V., VI., etc., tested for coronas by successive exhaustion gave the usual full series, beginning with diffuse dense fogs.

Table I. gives a summary of these results, among which may be mentioned the following: The insulation is not above $a = .01$ and usually lower. It is not exceeded when phosphorus nuclei have access merely by diffusion (VII.) nor on being blown in from a wide vessel (VIII.), the charge vanishing on the way. The leakage is not exceeded when a slow current of highly nucleated air stored over water, is passed through the condenser (V.), and but slightly for the case of a fast current of such nucleated air (VI.) taken out of the receiver or condensation chamber.

By contrast the excessive ionization ($a = .2 - .3$), if the original nucleation is at once introduced into the condenser, is striking enough. Hense less than 3 per cent. of the original ionization has survived after short storage in the receiver, in spite of the extreme

and undiminished density of nucleation which the coronas cotemporaneously show. In fact the ionization dies out almost at once in the condenser (XIII.–XIV.), even in the absence of water vapor.

9. *Further Data.*—The experiments were now repeated and the résumé of results shown in Table II. These are substantially like the above. With fresh phosphorus the residual ionization of the nuclei bearing air after short storage over water is but a few per cent. of the original ionization. It was supposed that on drying the nucleated air over phosphorus pentoxide, before passing it into the condenser the original ionization might be in part regained, but the table shows not a trace of this.

TABLE II.

Conduction of room air aspirated over phosphorus directly or indirectly into condenser.

Remarks.	$a \times 10^3$ Observed.	$a \times 20^3$ Corrected.
Insulation (room air).	8–10	0
Filtered damp air.	11	0
Nucleated damp air (fresh phosphorus).[1]	24	14
Do., partially dried.[1]	21	11
Do., older phosphorus.[1]	17	7
Do.[1]	18	8
Phosphorus nuclei at once into condenser.[2]	260	250
Do.[2]	290	280

The charge in the condenser is negative as before. It should be more rapidly dissipated if negative ions are precipitated more rapidly in the receiver, than a positive charge. To obtain dense nucleation room air was again aspirated over phosphorus into the receiver, from which it was then discharged as expeditiously as possible, the time taken being about five minutes.

10. *Effect of Different Charges in the Condenser.*— In the next experiments the sign of the charge in the condenser was varied. To find comparable results it was thus necessary to maintain a definite current through the condenser and about 2.5 liters per minute was adopted compatibly with the dimensions of the apparatus. Nuclei were again aspirated into the receiver over phosphorus. The leakage was apparently different for charges of opposed sign; but this

[1] From ionizer, to condensation chamber, to condenser.

[2] From ionizer, to condenser. A faster air current would increase this conduction.

was due to the insulation of the condenser, which is greater for negative than for positive charges. Deducting this the values of the ionization a differ by quantities which lie within the errors of observation.

As the receiver in the course of the efflux of nucleated air shows fogs of continually increasing density, the spontaneous precipitation must have been equally effective for positive and for negative nuclei.

TABLE III.

Conduction of room air, aspirated over phosphorus into condensation chamber and thence to condenser. Air current 2.5 *lit./min. charge at* 10 *volts.*

Charge in Condenser.	Conduction Observed.	Conduction Corrected.[1]
Negative.	$a = .025$	$a = .009$
Positive.	22	6
Positive.	22	6
Negative.	18	8
Positive.	24	8
Negative.	17	7

In Table IV. similar results are given, but with the insulation tested after each passage of nucleated air through the condenser.

TABLE IV.

Conduction of room air aspirated over phosphorus, through condensation chamber into condenser. Air current 2.5 *lit./min. charge at* 20 *volts.*

Charge in Condenser.	Conduction Corrected.[2]	Mean a.
Positive.	$a = .009$	.010
Negative.	12	
Positive.	09	
Negative.	09	
Positive.	11	

There is slight excess of leakage for negative charges; but as the insulation was $10^3 \times a = 9$–12 for positive and 1–2 for negative charges, these differences are within the uncertainties of observation.

One may again note that if the dense spontaneous fogs in the receiver were associated with selective condensation, then negative charges should be more rapidly dispelled.

[1] Insulation $10^3 \times a = 10$–16.

[2] Insulation tested after each passage of nucleated air.

11. *Dried Emanation.* — In the following experiments, Table V., the phosphorus was previously dried over calcic chloride, and then introduced into the receiver from the desiccator and the shortest possible connecting tube. Dry ions thus *suddenly* come in contact with water vapor, and it was supposed that an *unequal* reduction of positive and negative ionization might ensue. The ions were stored less than five minutes in the receiver, the shortest time practicable. Insulation of the electrometer and parts were determined before and after each measurement with nucleated air.

TABLE V.

Conduction of desiccated room air, aspirated over dried phosphorus, through condensation chamber, into condenser. Air current 2.5 *lit./min.*

Charge in Condenser.	Conduction Observed.[1]	Conduction Corrected.
Positive.	$a = .0152$	$a = .0023$
Negative.	.0070	22
Positive.	.0135	41

Contrary to all expectations the residual ionization so obtained, $a = .002–.004$ for positive and .002 for negative charges, is smaller than heretofore, but again practically neutral. Thus very dry phosphorus nuclei seem to lose their ionization quicker than if placed in ordinary air. The activity of the ionizer may account for the difference.

12. *Wet Emanation.* — For contrast, the nuclei were conveyed

TABLE VI.

Conduction of moistened room air, aspirated over phosphorus to the condensation chamber,[1] thence into condenser. Potential 20 *volts. Air current* 2.5 *lit./min.*

Charge in Condenser.	Conduction Observed.	Conduction Corrected.
Positive.	$a = .0207$	$a = .0109$
Negative.	.0117	.0046

into the receiver (Table VI.) in a wet current of air passing over phosphorus. A **U**-tube was used, one leg of which contained wet sponges and the other the phosphorus grid, the damp air from the former sweeping over the latter, into the receiver. The ionization

[1] Tested for coronas the nucleated air showed the usual strength.

found is distinctly greater[1] than the dry air data of the last table though it does not exceed the usual values for room air. The difficulty of keeping the ionizing activity constant is again involved.

According to the table, positive charges are more rapidly discharged than negative charges, that would indicate an excess of negative ions comparable to the case of water nuclei in the next chapter.

13. *Residual Ionization After One Hour.* — The storage of phosphorus nuclei over water in the above experiments did not exceed ten to fifteen minutes. It was thought that by giving the fog particles more time to subside, the sign of the residual ionization might become apparent, supposing that more negative nuclei are precipitated. The results in Table VII. are peculiar; whereas the positive charges in the presence of the nucleation vanish more slowly than for room air, the negative charge vanishes much faster. This would make an excess of $a = .005$ of residual positive nucleation over the negative nucleation, and it would follow that the negative nuclei are precipitated faster. But with a leakage in the electrometer of .011 and .004 respectively, without any ionized medium, the result is not guaranteed, particularly as the positive leakage is large.

TABLE VII.

Residual ionization of phosphorus nuclei, stored 1 *hour over water. Charge in condenser at* 20 *volts. Air current* 2.5 *lit./min.*

Charge in Condenser.	Conduction Observed.	Conduction Corrected.	Remarks.
Positive.	$a = .0121$	$a = .0000$	Room air.
Positive.	.0107	$-.0014$	Nucleated air.
Negative.	.0068	$+.0032$	Nucleated air.
Negative.	.0036	.0000	Room air.

14. *Nucleation Partially Precipitated.* — The nucleated air stored over water in the receiver was suddenly cooled and allowed to subside five to ten minutes. In this way greater chance was given for the differentiation of positive and negative nuclei. The corrected values of a, Table VIII., show that positive charge is removed faster than negative charge, by $a = .0010$ and .004, respectively, implying excess of negative nuclei. With the insulation varying from .003–

[1] Cf. Am. Journ. of Science (4), XII., p. 327, 1901.

.010 and .003–.013, before and after, some of the measurements, this result is again doubtful. It should be noticed that it is the reverse of the preceding.

TABLE VIII.

Residual ionization of phosphorus nuclei, after partial precipitation. Charge in condenser at 10 *volts. Air current* 2.5 *lit./min.*

Charge in Condenser.	Conduction Observed.	Conduction Corrected.	Remarks.
Negative.	$a = .013$	$a = .004$	Nucleated air.
Negative.	.015 and .003		Room air.[1]
Positive.	.022	.014	Nucleated air.
Positive.	.013 and .003		Room air.
Negative.	.019	.010	Nucleated air.
Negative.	.009 and .008		Room air.

15. *Ionization of Dry Phosphorus Nuclei.* — In the present experiments a dry vessel of ten liters capacity was introduced between the desiccator and the phosphorus tube. Phosphorus nuclei were now aspirated thence into this vessel. They were discharged after five minutes into the condenser after removing the phosphorus tube. Table IX. shows that almost all the ionization is lost by this dry storage, as the excess of leakage due to the discharge of this dry air through the condenser is $a = .000$ and .007, respectively. Thus dry air shows no preservative effect.

TABLE IX.

Residual ionization after dry storage (2*m*–5*m*) *of phosphorus nuclei. Charge in condenser at* 10 *volts. Air current* 2.5 *lit./min.*

Charge in Condenser.	Conduction Observed.	Conduction Corrected.	Remarks.
Negative.	$a = .006$	$a = .000$	Nucleated air.
Negative.	.006		Room air.
Positive.	.011	.012	Nucleated air.
Positive.	.004		Room air.

Intense ante-coronal fogs were obtained in the condensation chamber, due to incidental back aspiration of nuclei through the desiccators.

In Table X., by a modification of the apparatus, a current of dry air passes from the desiccator over phosphorus, and then into one

[1] Insulation given before and after experiment with nucleated air.

end of a dry vessel of ten liters capacity. At the other end of the vessel the air is continually discharged into the condenser. But the usual negative result appears.

TABLE X.

Residual ionization after continuous passage of phosphorus nuclei through a large dry vessel. Air current 2.5 lit./min.

Charge in Condenser.	Conduction Observed.	Conduction Corrected.	Remarks.
Negative, 20 volts.	$a = .017$	$a = .017$	Nucleated air.
" " "	.000		Room air.
" 30 "	.012	.012	Nucleated air.
" " "	.000		Room air.

INFERENCES.

16. *Inferences.* — The chief result of the investigation is the immensely rapid initial reduction of the ionization of the phosphorus emanation in contrast with the relative persistence and constancy of the nucleation. In other words only a few per cent. of the original ions are usually associated with the nuclei by which the dense fogs and coronal sequences are produced, even at the outset. It was with a view to possibly restoring some of this lost ionization that the great variety of experiments detailed in the chapter were undertaken.

Moreover, the whole of the original ionization vanishes symmetrically, for the nuclei as a whole are neutral throughout. At least with so insignificant a residue of the original ionization, the decision as to whether more positive or more negative ions have vanished is a delicate one and perhaps of trifling interest in this connection. For the phenomena are now all of the order of the leakage of the electrometer and appurtenances. If when 100 ionized nuclei of the phosphorus emanation are suddenly introduced into an atmosphere saturated with water vapor, the ionization of 96 has vanished without a record, while the remaining four are in equal number positive and negative, it is unlikely that negative ions can have greater affinity for water vapor or be more remarkable in their efficiency as condensation nuclei than positive ions.

Finally it does not appear that the ionization lost so soon after the removal of the emanation from the phosphorus surface can ever

be restored, notwithstanding the fact that in the condensation chamber, nuclei may be made to pass from the fog particle to the nuclear stage of size and density, an *indefinite* number of times.

That the original nucleation immediately at the phosphorus surface is so enormously reduced in number as to correspond to the loss if ionization; *i. e.*, that but a few per cent. of the initial number of nuclei can in any event be used for condensation, seems scarcely credible, though direct experiments would be difficult to devise with phosphorus. Placed in the condensation chamber over water phosphorus emits a dense filament of smoke and is relatively inefficient. All this would complicate the question uselessly. With water nuclei, however, the decision may be reached; for the nuclei are most effectively produced in the condensation chamber itself, while the ionization may be studied without loss of time; and here it makes no appreciable difference whether a corona is produced at once after the jet has been shut off, or after the short time needed for the ionization practically to vanish. The aperture and type of the corona and hence the number of nuclei involved are the same.

BROWN UNIVERSITY, PROVIDENCE, R. I.

EFFECT OF HEAT ON EXCITED RADIOACTIVITY.

BY FANNY COOK GATES.

RECENT experiments on the nature of excited radioactivity have shown that by various mechanical and chemical means the radioactivity may be removed from the surface on which it is found, but no proof has been given that it can be destroyed by such treatment. On the contrary, when an excited wire loses its activity by friction, the substance with which it is rubbed becomes radioactive to a degree corresponding to the loss from the wire. When attacked by acids, the radioactivity lost from the wire is found in the solvent.

Professor Rutherford has found that a platinum wire excited by thorium emanations can be made red hot without appreciably changing its activity, but that the activity is almost entirely lost after heating the wire to incandescence. This sudden disappearance of the radioactivity at white heat seemed to furnish evidence of its destruction, and with the aim of either establishing or refuting such a view the following experiments were undertaken.

If the excited radioactivity is not destroyed by intense heat, it was argued that by heating the wire inside a closed vessel so as to prevent all escape, the active particles, although removed from the wire, would still remain and might be discovered in the surrounding air or on the walls of the vessel. For this purpose a hollow brass cylinder about ten inches in length and three inches in diameter was fitted with ebonite ends; in each end were two openings, one in the center through which to pass the wire, and another through which to send a blast of air when desired. The wires used were six inches in length and about one twentieth of an inch in diameter. The cylinder was used in the usual manner, as a testing vessel for measuring the amount of radioactivity within it. Its outside was joined to one terminal of a storage battery of 100 volts, and the

central wire to one pair of quadrants of an electrometer of which the other pair was connected to earth. Another testing vessel was used for comparing the amounts of activity produced by the wire before and after heating.

The wire was excited by making it the cathode of a P.D. of 100 volts and placing it for several hours inside a closed metal box containing 50 grams of thoria. When placed in position in the cylinder, an ionization current of the order of 10^{-11} amperes was produced. A current of 20 amperes was then passed through the wire, heating it to incandescence, after which the ionization current was again measured. Instead of showing a great loss, as might have been expected, the current was nearly as large as before; upon replacing the platinum wire by an inactive copper wire but little further

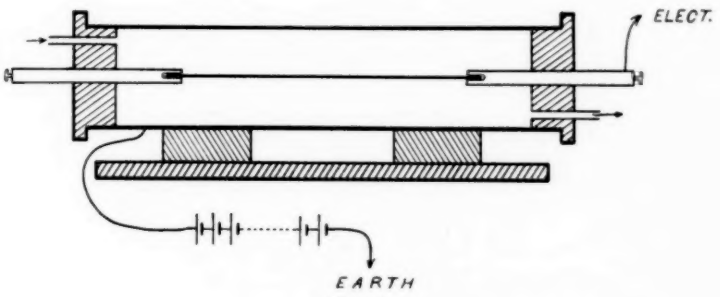

Fig. 1.

change was observed. The platinum wire was then put in the second testing vessel and found to possess only about 3 per cent. of its original activity. Clearly then the active particles had been removed from the wire and were still inside the cylinder. The air was then blown out but no decrease in current was thereby obtained, showing that the active particles had become attached to the inside surface of the cylinder. The rate of decay of the radioactivity within the cylinder was observed and found to be such that it was reduced to half value in eleven hours, the characteristic of excited radioactivity from thorium.

From these results we conclude that *intense heat does not destroy excited radioactivity*, and that under conditions as here described the active particles are transferred at a definite temperature without other change from the platinum wire to the inside surface of the cylinder,

The tests were repeated with wires excited by radium emanations with similar results, although on account of the rapid decay of the excited radium radioactivity during the first fifteen minutes, the tests had to be confined to the period between 15 and 35 minutes after the removal of the wire, since the rate of decay is known to be a minimum during this interval.

Some of the results of several sets of these observations are given in tabular form on a following page. (Table I., 1–4.) It cannot be assumed that, if all of the active particles were transferred from the wire to the cylinder, the ionization current would necessarily be unchanged, since in the latter case the radiations are not all radial as in the former. It would be difficult to determine experimently how great a change this produces, but it is doubtless large enough to account for the slight numerical difference between the current before and after the wire is heated, when we also consider that some of the active particles may have escaped through the ends of the cylinder with the sudden outrush of heated air.

In order to get from the wire to the cylinder the active particles must have been in the air at some time, and since none could be blown out later, all must have been transferred during the heating. This was shown experimentally to be the case by the fact that the particles could be blown out of the cylinder while the wire was being heated, although at no other time. A strong blast of dust-free air was directed along the wire all the time it was being heated. Although this so cooled the wire that fewer particles were driven from it than in the preceding tests, the activity within the cylinder was reduced to less than one third its original value, showing that over two thirds of the particles had been driven out of the cylinder. It was found possible to blow the particles from one cylinder into another.

An attempt was made to observe the effect produced by blowing and heating in the presence of a strong electric field with the object of ascertaining the nature of the charges carried by the particles, but no definite conclusions were attained.

Two views may be taken as to the cause of the removal of the active particles from excited platinum at white heat:

1. Their removal may be due to a volatilization of the active material.

2. The platinum may itself disintegrate and carry the active particles with it.

It is known that platinum when white hot undergoes a surface disintegration in air, and the remarkable disappearance of the radioactivity at about this temperature is in harmony with the view that the active particles were carried off with the outside disintegrated film of the wire. If this were the true explanation,

TABLE I.

Heating without blowing.

Exp. No.	Wire Used.	Excited Radioactivity Due to	Activity from Wire Before Heating.	From Cylinder and Wire After Heating.	From Cylinder Alone After Heating.	From Wire alone After Heating.	Difference.
1	Platinum.	Thorium.	100	90	87	2	10
2	"	"	100	92	90	2	8
3	"	"	100	94	—	—	6
4	"	Radium.	100	92	88	2	8
5	German silver.	"	100	98	33	66	2
6	Plat. iridium.	Thorium.	100	97	81	15	3
7	Plat. in CO_2.	"	100	98	95	3	2
8	Plat. in H.	"	100	95	89	6	5

TABLE II.

Blowing while heating.

Exp. No.	Wire Used.	Excited Radioactivity Due to	Activity from Wire Before Heating.	From Cylinder and Wire After Heating.	From Cylinder Alone, After Heating.	From Wire alone After Heating.	Amount Escaped.
1	Platinum.	Thorium.	100	36	20	18	64
2	"	"	100	36	10	13	64
3	"	"	100	38	20	18	62
4	"	"	100	22	16	6	78
5	"	Radium.	100	25	—	—	75
6	"	"	100	23	15	8	77
7	Plat. iridium.	"	100	45	31	14	55

wires of other material, or even platinum wires when surrounded by other gases, should not show the same effects.

German-silver and platinum-iridium (10 per cent. iridium) wires were used instead of platinum, but although the wires lost less of their activity in these cases, the behavior of the liberated particles was the same as that of those expelled from platinum. When the

wire was heated in carbon dioxide instead of in air, it lost 97 per cent of its radioactivity, and nearly as much when heated in hydrogen. (See Table I., 5–8; Table II., 7.)

These results seem to completely refute the theory that a disintegration of platinum is necessary to cause the transfer of the excited radioactivity from the wires to the walls of the surrounding vessel and to point to the conclusion that, at the temperature of white heat for platinum, a volatilization of the active material itself takes place.

During the course of the above observations an interesting effect was noticed which has not been mentioned. When measurements of the ionization current were made immediately after heating, the current was always much less than the value which it afterward attained, sometimes being only a third that amount. It would then steadily increase for twenty or twenty-five minutes when the maximum was usually reached. It can easily be supposed that part of this effect is due to the cooling of the air since the ionization current varies inversely as the absolute temperature, but neither could so large a change be accounted for on this ground alone, nor would the current increase for so long a period. The phenomenon is completely explained by assuming that the air in the cylinder after heating is filled with particles of disintegrated platinum and other matter, which behaving as dust particles increase the rate of recombination and decrease the current for a given voltage. That this assumption is correct was shown by blowing a current of dustless air through the cylinder immediately after heating. The values which otherwise required twenty minutes to be reached, were attained immediately.

SUMMARY OF RESULTS.

1. Excited radioactivity cannot be destroyed by heat.

2. The active particles are removed from platinum and other wires at a temperature just below white heat, and are transferred unchanged to the surfaces of the cooler solids near.

3. By removing the surrounding gas as fast as the wire is heated, a large portion of the active particles may be carried off with it.

4. The removal of the excited radioactivity from the wire is probably due to a volatilization of the active material.

I desire to express my gratitude to Professor Rutherford through whose kindness the privileges of this laboratory have been extended to me, and under whose direction these experiments have been performed.

MACDONALD PHYSICS BUILDING,
McGILL UNIVERSITY, MONTREAL, January, 1903.

RADIOACTIVITY OF FRESHLY FALLEN SNOW.[1]

S. J. ALLAN.

C. T. R. WILSON has shown that freshly fallen rain is radioactive and that its activity decays rapidly with time. It seemed probable that freshly fallen snow would also show this effect. During the first snow storm of the season about a liter of snow was quickly collected from a thin layer on the surface, and evaporated down to dryness in a shallow tin dish. This dish which before filling with snow had been tested, and found to contain no trace of radioactivity was now able to ionize the air in its immediate vicinity quite strongly.

The apparatus used to test the presence of the activity is shown

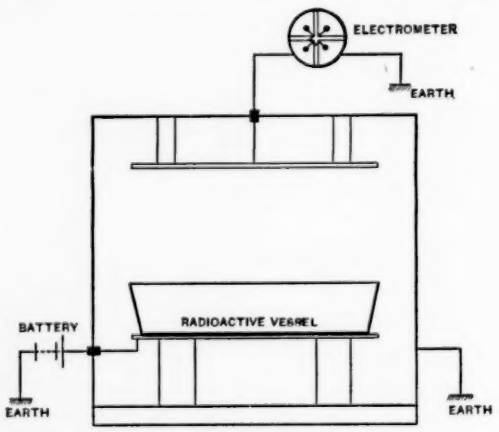

Fig. 1.

in Fig. 1 and consisted as follows: Two parallel zinc plates were suspended one above the other and both insulated. The upper plate was connected to one pair of quadrants of a sensitive electrometer, the other pair being earthed. The electrometer was of the usual type with upper and lower quadrant plates. The needle was of thin aluminium suspended by bifilar silk fibers. It was kept continually

[1] Communicated to American Physical Society January, 1903.

charged to 300 volts by a battery. When charged to this potential the electrometer needle gave about 600 scale divisions per volt, the scale being about 2 meters from the mirror.

The lower zinc plate was connected to one pole of a battery of small accumulators from which any voltage up to 300 could be obtained. The other pole of the battery was earthed. These two plates were enclosed in a zinc box connected to earth, which served as a guard ring. By operating a key from a distance, by means of a string, the quadrants could be separated. The radioactive vessel was place on the lower plate. The rate of movement of the needle was thus a measure of the activity present. There was always a small leak, due to the natural ionization within the apparatus. As this was only .2 of a scale div. per sec., any increase in the ionization current, due to a radioactive substance being present could easily be detected. A specimen of uranium was kept as a means of standardizing the apparatus.

A great many tests were made extending over about six weeks. The snow was always collected from a thin layer on the surface, so as to get that which had recently fallen. It generally took from twenty to thirty minutes to collect, evaporate down and test. The activity had thus fallen in value during this time.

Two of the best methods of distinguishing between the various types of radiations are the rate of decay and the penetrating power in various substances. These two methods were therefore tried. Numerous tests on the rate of decay showed that it followed closely a geometrical progression with time, falling to half value in about thirty minutes. This rate of decay was never found to vary appreciably. Some of these results are plotted in the accompanying curves (Fig. 2). Curves *A* and *B* are from observations taken on the same day, *A* from one liter of snow and *B* from one half liter. The fall of snow on this day was heavy and thick, and gave the greatest amount obtained during any snow storm tested. Curve *C* shows one taken on another day when the fall of snow was much lighter. It is the amount obtained from one liter. In some of the tests the snow had been falling for several hours and in others only a short time. All of these curves show the activity to fall to half value in about thirty-two minutes. In curve *D* are plotted results,

taken from a test on the rate of decay of excited activity on a negatively charged copper wire in the open air. These are plotted on the same scale for sake of comparison. It will be seen that this falls to half value in about forty-eight minutes. There is thus a distinct difference in the rate of decay of the two activities.

Tests were made on the penetrating power of the activity from snow. For this purpose the activity was rubbed off onto a piece of leather, moistened with ammonia. The leather was then covered with sheets of thin aluminum foil, and the rate of leak taken when covered and uncovered. From these results the penetrating power

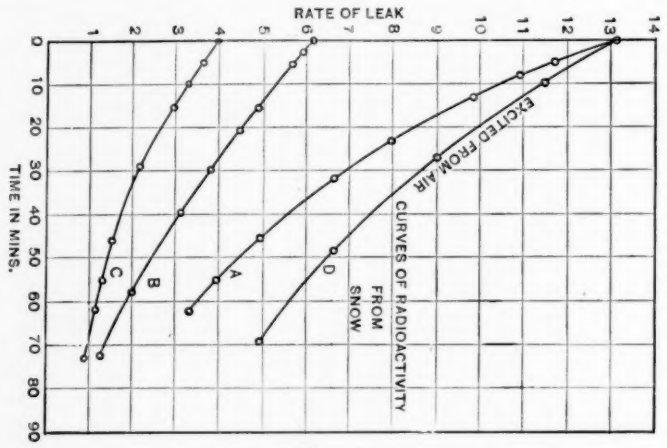

Fig. 2.

could be calculated. It was found to be about the same as for the excited activity from air, half of it being absorbed in .00076 cm. of aluminum.

In many other respects this activity behaved like the excited activity from air. If the activity was rubbed off onto a piece of cotton, which was then burnt to ashes, the residue was still radioactive. It could be heated to a bright-red heat without destroying any appreciable amount of its activity. It was found that during a steady fall of snow the amount of activity that could be obtained from a given amount of snow remained about constant, and no such thing as an exhaustion of the atmosphere could be observed. Twenty-four hours after a heavy fall of snow a very small amount could be still obtained. Experiments were tried to see whether

the decay was the same in the snow as when the snow was evaporated down to dryness. Owing to difficulties encountered nothing definite could be obtained.

The amount of activity obtained from a liter of snow was about equal in effect to one fifth of a gram of uranium. It might be of interest to show the amount that could be obtained from a square mile of territory, covered with a layer of freshly fallen snow 1 cm. thick. The maximum ionization current obtained from a liter was about twenty scale divisions per second. With this apparatus each scale division corresponds to about 3×10^{-13} amperes. From a square mile we ought therefore to obtain roughly about 1.5×10^{-4} amperes per second. This is a considerable amount and could be easily measured with a galvanometer, so that during a heavy fall of snow over a territory the size of Canada, a considerable amount of energy would be represented in the activity.

From the results of this investigation two general conclusions may be drawn: either that this activity is different from the excited activity from air, or that the excited is of a more complex character than was at first supposed. We know nothing as to the mode of production of the radioactivity in air. There may be several processes going on, each manifesting itself under different conditions, of which the activity in snow may be one. The rate of decay of the excited on a charged wire may be the resultant of several rates of decay, and that from snow one of them. In all other respects the two activities give the same results, the rate of decay being the only difference. Since this paper was first communicated, investigations by the author on the rate of decay of the excited activity from air on copper wires have brought out some interesting results. The activity was rubbed off from the wire, with the aid of ammonia, on to various materials, such as leather and felt. The activity on the leather fell to half value in thirty-eight minutes, whilst on a piece of absorbent felt it took sixty minutes to fall to half value. If a piece of cotton was rubbed over the wire, and then reduced to ashes, the activity on it fell to half value in forty-five minutes, the same as on the wire itself.

Investigations are at present being continued on the rates of decay of the activities from air, snow and rain. These may throw

some light on the difference betweeen the rates of decay of the radioactivity obtained from the air by these methods.

It seems probable that there is in the atmosphere some process going on producing positive radioactive carriers, since they are only collected on a negative wire. The particles of snow would act as collectors for the radioactive carriers, removing them from the air. The amount of activity which reached the ground with the snow would depend on the closeness together of the snowflakes, and on the rate at which they fell.

MACDONALD PHYSICS BUILDING,
McGILL UNIVERSITY, MONTREAL, January, 1903.

NOTE.

Ogden Nicholas Rood.—Ogden N. Rood, son of the Reverend Anson Rood, was born at Danbury, Conn., on the 3d of February, 1831. He was graduated from Princeton College in 1852 and spent the two following years in part as a graduate student at Yale and in part as an assistant at the University of Virginia and as assistant to Professor Silliman in New York. In 1854 he went to Germany for further study.

During his four years' residence abroad (1854–58) Rood, in addition to his scientific study, devoted much time to the practice of oil painting. He had a natural taste for art and music and took advantage of the great opportunities afforded in Berlin and Munich for the development of his talents. In 1858 he married Miss Prunner, of Munich, and in the same year returned to America and began his career as a teacher in the Troy (N. Y.) University.

Before going abroad Rood had already published two papers on microscopical subjects. During the five years which he spent in Troy he completed a series of experimental investigations chiefly on light, which were printed in the *American Journal of Science.* In 1864 the chair of physics in Columbia College became vacant and he was appointed to the professorship in that subject, which position he held up to the time of his death, on November 12, 1902.

Rood's work during his residence in Troy, which included, in addition to the optical experiments already mentioned, an elaborate research on the performance of projectiles, and likewise a series of papers on the application of photography in physical investigation, received prompt and cordial recognition on the part of men of science at home and abroad, and in 1865 he was elected to the newly-established National Academy of Sciences. His unusual skill as an experimenter was specially shown by his success in obtaining measurements of extreme accuracy and delicacy by comparatively simple appliances. In his measurements of the changes of the dimensions of bodies by means of the horizontal pendulum, in 1874, he was able to attain a degree of sensitiveness fully equal to the best performance of the interferometer. By the use of the revolving disc he determined with great accuracy the duration of the electric spark and of the lightning flash, demonstrated the multiple character of lightning and estimated the minimum time of illumination capable of producing distinct vision. When, in the seventies, the work of Toepler

and of Crookes upon the electric phenomena observed in high vacua was attracting the attention of the scientific world, Rood turned his attention to this fascinating subject. In 1876 he published a paper on the force involved in Crookes' radiometer. In 1880 he described an improvement in the Sprengel pump, and in the following year he brought out his paper on a method of obtaining and measuring high vacua with a modified form of the mercury pump. Few problems are better adapted to test the skill, ingenuity and patience of an experimenter than that of attempting to produce the highest attainable vacuum, and no one, probably, among the numerous workers in this difficult field has recorded the measurement of a lower pressure ($\frac{1}{1\,390\,000\,000}$ of an atmosphere) than that attained by Rood in this research. While later determinations have thrown into serious doubt the accuracy of such measurements by means of the McLeod gauge, it is safe to say Rood pushed his investigations to the very limits of human possibility.

The period of Rood's greatest scientific activity lies in the twenty years between 1860 1880. His attention, during these years was chiefly, although by no means exclusively, directed to physiological optics and especially to the subject of color. His long-continued studies in this field were embodied in the well-known volume entitled "Modern Chromatics" which he published in 1879 and which was reissued later under the less appropriate title of "A Text-book of Color." This little book will ever be a delight to students of color. The treatment is admirable in its directness and simplicity, in which respect it reminds one of the popular works of Tyndall. It is like the work of Tyndall also in being no mere compilation of the results of others and in consisting of original experiments described in language intelligible to every educated reader. The book has a double charm. On the one hand, it is good physics, while on the other, it is enriched throughout by the author's artistic experience and enlivened by his enthusiasm for the beauties of color as observed in nature. The subjects of color mixture, of contrast, of change in luminosity, and of color gradation are illustrated by descriptions of the effects observed in the landscape. These are matters of which Rood was entitled to speak from the standpoint of both artist and physicist. Painting in oil and water colors was with him a passion. It was a pastime to which he devoted much of his leisure, and by means of which his powers as an observer of the phenomena of color as displayed in nature were developed in an extraordinary degree. The development of the æsthetic and artistic side throughout the work is systematic and progressive. The book begins with the pure physics of color and goes over gradually to the consideration of the application of the principles in art. The concluding chapter on the use of color in painting and decoration, although brief, is one of the most interesting and suggestive contributions to this subject which has ever been written.

After 1880 published contributions to science from the hand of Rood became comparatively infrequent, but the falling off was of quantity only and not of power. In 1893 he brought out a new principle in photometry of great theoretical interest and practical importance, the soundness and utility of which was subsequently further corroborated at the hands of Whitman and others. In 1900 he published a second important contribution to this subject in which an ingenious form of the flicker photometer was described. In 1896 he published a paper on the reflection of X-rays, and in 1900 and 1901 he made his final contributions to science upon the measurement of very high resistances.

Among the notable characteristics of Rood's personality were his disdain for the commercial and industrial aspects of physics, and his scarcely less intense dislike of ostentation and publicity. Always more or less inclined to be a recluse, the love of retirement seemed to grow upon him with the passing years. Instead of yielding, like too many others, to the demands of the time for something practical and utilitarian, he resisted absolutely the influence of the philistine atmosphere of the great city in which he lived and clung resolutely to the ideals of pure science.

E. L. N.

NEW BOOKS.

Physics. By FREDERICK SLATE. Pp. i + 404. New York, The Macmillan Company, 1902.

High School Physics. By CARHART & CHUTE. Pp. i + 424. Boston, Allyn & Bacon, 1902.

Elements of Physics. By FERNANDO SANFORD. Pp. i + 414. New York, Henry Holt & Company, 1902.

It will perhaps be generally admitted that the success with which students may pursue the subject of physics is more largely a function of the teacher than of any other objective condition: and yet it must be conceded that the text-book employed is a condition not entirely devoid of influence. Such a book is, therefore, always interesting from at least two points of view; first, as giving us an almost infallible judgment as to the author's conception of the great body of truth which is to-day grouped under the head of physics; and secondly, as a message from the author to teachers of physics. The first point of view is a purely psychological one, the second, a purely pedagogical one.

It is in this second regard, viz: the message from the author to the instructor, that lies the chief merit (and perhaps also the *raison d'être*) of many of our text-books. The fact that the book serves the student as a compendium of fact and as a syllabus of the subject is merely incidental as compared with the influence of the book upon the teacher, who actually handles the class. The student's intellectual growth and his ideas of the subject depend so much more upon the teacher's point of view and his mode of presentation than upon any other factor that, in most classes, a text-book might easily be changed without producing a ripple upon the mental surface of the class.

Looked at from this two-fold viewpoint, three interesting volumes have recently made their appearence in the high school world.

We shall consider first Professor Slate's "Physics." This book is characterized, above all else, by the author's philosophical view of the subject; even the simplest phenomena are made interesting in the light of the philosophy which underlies them. The really deep insight into the physical processes of nature and the keen epistemological appreciation of the author combine to make the volume well worth reading to every instructor of physics. Illustrations in the form of diagrams are rather

meagre; but the illustrations of principles by means of citation of familiar phenomena are so abundant as to form one of the marked features of the book. As to English, the phrasing is at times very effective; take, for example, the description of "weight" (p. 219) as "a partnership effect in which earth and body are both concerned." As a rule, however, the style, while clear, is involved; it is by no means so simple as it might be, and is, therefore, less adapted than it might be to the grade of students for which the book is intended.

Another feature which serves to give this volume a marked individuality is the entire omission from its pages of such simple mechanical ideas as centrifugal force, simple harmonic motion, wave motion, Newton's laws of motion (except implicitly); not to mention such minor (?) subjects as thermo-electric currents, E.M.F. due to cutting lines of force, the idea of electrostatic quantity, electrostatic capacity. The manner in which the use of these terms is avoided, and the proper idea still conveyed, is always clever and often ingenious. One cannot help feeling, however, that even this skillful author now and then realizes the need of some of these well tried tools of the profession. Witness the following explanation (p. 221) of the diminution in the acceleration of gravity as one approaches the equator. "The earth is turning on its polar axis once in twenty-four hours, the consequence being that gravitation at any place is active *in other ways than in adding to the speed of falling bodies*, and that the value of g is smallest at the equator, where the other demands upon gravitation are greatest." The phrase we have placed in italics is the one by which the use of centrifugal force is neatly avoided.

The clever explanation of musical quality (p. 234) without the use of the word "wave" is certainly clear to one who already understands the explanation; but whether the average beginner would comprehend the idea without several re-readings is perhaps doubtful. The frequent use of the principle of minimum potential energy is an admirable feature. In a certain sense the discussion of mechanics is distributed throughout the entire volume. This accords perhaps with the fact that most successful teachers of physics find it necessary to make constant reference to the chapters on dynamics.

On the whole, this excellent treatment impresses your reviewer as somewhat in advance of the demands of the times; but not at all in advance of the needs of the times. The clear and scholarly unitary view of the subject which is here presented is certain to prove helpful both to teacher and taught until the present viewpoint of the physicist has been decidedly modified.

The excellent *High School Physics* of Professors Carhart and Chute, although appearing under a slightly changed title, is really only a new edition of their *Elements of Physics*, which has for many years enjoyed

a well-deserved popularity. The reason which the authors give for making any changes is the following: "The advances in physics are so rapid and the point of view from which many topics are now considered is so different from that of half a dozen years ago that it seemed best to make an entirely new book rather than a revision of the former one."

We select the following as fairly representing the trend of these changes:

1. Matter is no longer defined as "that which occupies space." Indeed any ability to define it at all is distinctly disavowed, and the student is referred to the study of the various properties of matter as yielding the best notion of what matter is.

2. Those convenient little bodies, called atoms and molecules, are given a much less prominent place in the earlier pages.

3. The discussion of surface tension has been transferred from the first chapter to the chapter on the "Mechanics of Fluids," where it undoubtedly belongs.

4. The term "speed" is introduced to denote the scalar factor of velocity.

5. The chapter on Sound is removed from the latter half of the work and is placed in a much more natural position, immediately following Mechanics.

6. The three statements concerning spectra hitherto honored by the title of "Laws" and printed in italics, have been robbed of their former dignity, degraded to the ranks of common type, and confined to a single portion of a single paragraph. Certainly no one will doubt the wisdom of this change.

7. The introduction of the definition of the electrostatic unit of quantity makes possible a logical definition of electrostatic capacity which was impossible in the earlier edition.

The above changes are perhaps sufficient to characterize the improvements introduced into the new edition, though it must be confessed that they are hardly such as flow from any new "point of view" which has found its way into physics within the "last half dozen years."

The language of the text is simple, clear, and well adapted to the average high school student. The illustrations are excellent and almost without exception place the emphasis where it would appear to belong.

The introduction of the Nernst lamp, the oscillatory discharge, wireless telegraphy will doubtless be acceptable to the average high school teacher; at the same time, the better grade of high school instructors will probably find that those simpler phenomena which can be more thoroughly studied and comprehended by the student are not only the ones upon which the student will grow most rapidly in the power of clear thinking, but are also quite sufficient to cover the entire period of one year.

Professor Sanford's "Elements of Physics" represents, in an excellent way, both the concrete and the discrete presentation of the subject. It is concrete in the sense that most of the volume is occupied with certain definite and particular phenomena including 145 laboratory exercises for the student; while it is discrete in the sense that it minimizes (perhaps very properly) the general discussions and abstractions of the lecture room, and because there is found throughout the volume comparatively little "connective tissue," if one may so describe those general principles which make physics one subject instead of half a dozen. The prominence which is given to mechanics is pleasing to those who have faith in the unifying power of dynamics. On the other hand, there are some evidences of haste here and there which may easily be remedied in a second edition. For instance, one finds acceleration everywhere expressed in the same unit as velocity, namely, "centimeters per second." And again, it is difficult to see how the following statement of Newton's First Law (p. 36) harmonizes with the facts:

"Every body perseveres in its state of rest or uniform motion in a straight line unless it receives energy from or gives off energy to some other body." Such a statement assumes that when a body is neither receiving nor giving out energy, it is not acted upon by any force. That this is not the case may be seen in a uniformly rotating wheel where the energy and speed of each particle remain constant while the linear velocity of each particle is constantly undergoing change. The same would be true of a car moving without friction on a circular horizontal track.

The following definition (p. 138) will hardly meet the approval of those who believe that energy and matter are not conditions but objective realities. "In the study of physics, we define heat as the *physical condition which may give rise to the sensation of warmth in our bodies.*"

Again on page 268 we find electric force and electromotive force apparently interchanged. E.M.F. is defined as "a name given to whatever tends to move an electric charge," whereas E.M.F. is ordinarily (J. J. Thompson. Art. 173) defined as the line integral of this quantity.

The author's clearness and simplicity of style and the wealth of experimental illustrations which he has given will be appreciated both by students and teachers. While thoroughly up to date, the treatment is still marked by conservatism both in ideas and in nomenclature. But perhaps the volume is to be recommended above all else for its keen sympathy with the student and with the student's point of view, and by a realizing sense of the fact that acquisition of power by the student is the main object.

High school teachers everywhere are to be congratulated on having three such excellent volumes added to the already long list at their disposal.

HENRY CREW.

Die Electricität in Gasen. By JOHANN STARK. Pp. xxviii + 509. Barth, Leipzig, 1902.

In this volume the varied phenomena produced by the passage of the electric discharge through gases are brought together and are treated from the point of view of the ionic theory. Dr. Stark's book opens with a brief chapter on the apparatus and methods of experimentation. This is followed by a historical description of the ionic theory and by a very full discussion of the recognized methods by which ionization takes place. Part III. deals in a complete and detailed manner with the characteristic features of the electric current in gases and part IV. with the mechanism of the current considered from the point of view of the ionic theory. Under the general title of *ionic rays* the author describes the production and properties of kathode rays and canal rays.

Part VI. deals with the force by means of which the motions of ions are effected and the forms of energy which they may be regarded as possessing. The author considers the ion to have kinetic energy, magnetic energy, electric energy in so far as the ion possesses a field of electric force and finally potential or contact energy; which is defined as the energy which manifests itself when the ion without acceleration changes its molecular condition. This occurs for example whenever an ion passes out of the sphere of action of a metal surface and enters a region where it is acted upon by gas particles alone.

The volumes closes with a series of chapters upon the thermal, optical and chemical effects of ionization. Under the first of these heads are considered the variations of temperature within vacuum tubes, the heating of the electrode, the production of heat in the electric arc and in the spark discharge and the phenomenon of the disintegration of the kathode. Under the head of optical effects comes first of all the electric glow of gases when subjected to the discharge. This comprises, from the nature of the case, a complicated set of phenomena. We have, in the first place, radiation due to the temperature of the gas and also radiation which is ascribed to the impact of an ion against a molecule. Both positive and negative ions are to be considered as producers of radiation. In ionized gases, according to the author's view, there are in the most general case five different varieties of particles present. The neutral *molecule*, the *negative ion*, the *positive ion*, the *positive molion* and the *negative molion*. The molion is defined as an ion, which has taken to itself several neutral particles by virtue of mutual attraction. The molion may be either positive or negative according to the character of the ion in question. Radiation due to the negative ion is assumed to be identical with *Roentgen radiation*. The author regards the light produced by the two classes of molions to be so small as not to be observable in the spectrum of the glowing gas. He assigns gas spectra to two principal causes: First, To

the breaking up of a neutral molecule through impact with a positive ion (which is accompanied by an intense emission), and secondly to the impact of negative ions with molecules. The author inclines to the view that of the two spectra commonly observed in electrically glowing gases the line spectrum is due to the action of the positive ion while the band spectrum is produced by impact of the neutral molecules with one of the other of the two sorts of ions. Concerning the source of the continuous spectrum observed at high pressures no definite explanation is offered.

Considering the newness of this domain and the fact that widely different views are still held concerning the fundamental theories, the most that can be expected of the writer of any treatise on the phenomena accompanying the passage of the electric discharge through gases is that he shall give a fairly complete and intelligible account of our present knowledge of this important but very complicated department of physics. This Dr. Stark, in the volume under consideration, has done. His book is descriptive rather than controversial and its value is greatly enhanced by the very full set of references to original sources. These references of the literature are brought up to 1892 and it is especially gratifying to the American reader to know that the important contributions of Rutherford, Zeleny, Child, Barus, Graham and other physicists on this side of the water have been duly recognized. The absence of an index, a rare fault in German works, is especially unfortunate in the case of a volume containing so great a mass of detail. It is an omission that will be deplored by every reader. E. L. N.

Practical Electro-Chemistry. By BERTRAM BLOUNT. Westminster; Constable & Co.; New York, The Macmillan Company, 1901. Pp. xi + 374.

This treatise is practical in the sense that it deals for the most part with electrolytic processes on the large or commercial scale, such as the electrolytic winning and refining of metals in aqueous solution, in igneous solution, and in the electric furnace. The last-named section closes with a short description of the production of carbides, borides and silicides.

The foregoing matter which occupies nearly three-fourths of the entire volume is followed by short chapters upon electro-deposition, the production of alkali and chlorine and the electrolytic manufacture of organic compounds.

Finally there is an interesting chapter on *power* in which the relative claims of water and steam power are discussed and the various attempts to obtain energy cheaply by means of primary batteries in which the carbon is consumed are considered. The author appears not to have been acquainted with the work done by Case in this direction but the addition of that to his description of other investigations would have in no wise

vitiated his conclusion that "the present position of the problem of converting the energy of carbon into electrical energy by means other than the boiler, engine and dynamo is one of attempt, not of achievement."

Some idea of Mr. Blount's method of dealing with his subject may be obtained from the following brief summary on the chapter of copper, the refining of which is the largest of all electrolytic industries. After giving the analysis of the average sample of the crude copper, the usual size of anode and cathode is stated and their arrangement in the vat is shown by means of diagrams. The current density, difference of potential, composition of the electrolyte, together with the devices for regulating its flow, are considered at some length. Tables are given showing the quality of the product. The working of the anode sludge for gold and silver is briefly described and the value of this by-product, which in 1896 amounted, in the United States alone, to fourteen million ounces of silver and sixty-eight thousand ounces of gold is given. The chapter continues with the discussion of the various attempts which have been made to place the electrolytic production of a copper directly from the ore upon a successful commercial basis.

The other metals, the electrolytic production of which from aqueous solution is considered are lead, gold, silver, nickel, tin, antimony and zinc. In the section dealing with the winning and refining of metals in igneous solution the production of aluminium, magnesium and sodium are described. The author distinguishes between the electric furnace as developed by Cowles and Moissan and the devices for fusing the solvents used in the reduction of the foregoing metals, although the heat in the latter case is likewise obtained by means of the electric current flowing through the cell. Moissan's work with the electric furnace is very briefly and cursorily treated. It is true that his investigations are fully described in his recent book upon the electric furnace, but many readers of Mr. Blount's treatise will regret that somewhat more space was not given to the description of these remarkable and suggestive researches, which seem likely to have increasing technical importance. The products of electric furnace work described in this section are chromium, molydenum and tungsten which find their commercial use in the manufacture of special steels; and carbides of calcium and silicon. The remarkable properties of carbon boride are briefly described and the possibility that on account of its extraordinary hardness, the industrial preparation of this compound for use as an abrasive may prove remunerative is touched upon. The fact that graphite is produced in electric furnace work is alluded to but the electric production of graphite which has grown to be an important commercial matter in the hands of Acheson is not even mentioned. This is doubtless too recent a development to have found place in the present volume.

E. L. N.